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Artificialized land and land take

Drivers, impacts and potential responses

Maylis Desrousseaux, Béatrice Béchet,
Yves Le Bissonnais, Anne Ruas, Bertrand Schmitt, eds

éditions Quæ

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This book summarizes the collective scientific assessment report jointly requested by the Ministry in charge of the Environment, ADEME, and the Ministry of Agriculture and Food. The contents of the full report and the summary document are the sole responsibility of the authors. The overall report, forming the source of this version, was created in 2019 by the experts without the condition of preliminary approval by the sponsors, IFSTTAR (now université Gustave Eiffel) or INRA (now INRAE). The synthesis was validated by the authors of the report.

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Foreword

As a major reservoir of biodiversity, soils are essential for many ecosystem services such as food production, climate regulation, flood mitigation, water quality and air quality. Faced with growing and conflicting demands for housing, commerce, infrastructure, food, raw materials, energy and natural spaces, this limited and non-renewable resource is, at human time scales, subject to strong competition from use and pressures that may degrade quality or limit availability. In this context, 'land take' is often considered, even denounced, as one of the main drivers of soil degradation and loss of agricultural land but also of natural and forest areas.

Therefore, the public authorities attempting to regulate this phenomenon asked IFSTTAR and INRA to produce a Collective Scientific report (ESCo) which summarises the available scientific knowledge of the determinants and consequences of artificialized land and the policy tools that could limit its extension and/or environmental impacts. Supported by the Ministry in charge of the Environment (General Commissariat for Sustainable Development, CGDD, Ministry of Ecological and Inclusive Transition, MTES), ADEME (French Agency for the Environment and Energy Management) and the Ministry of Agriculture and Food (Directorate General of Economic and Environmental Performance of Enterprises, DGPE), this request has four components.

The first component is to try to evaluate the extent of land take in the French territory, relying on the scientific literature and the reports and statistical studies that underlie it, and to clarify the position of France in relation to other OECD (Organisation for Economic Co-operation and Development) countries.

Beyond these measurements, the question of the determinants of land take and of their possible hierarchy is central to understanding the evolution of this land-use change and to identify the land take trends taking shape.

In view of these challenges, it is also necessary to identify the impacts of the phenomenon, both on the biotic and abiotic environment and on the living conditions of populations and economic and social dynamics, with a specific focus on agricultural impacts.

Lastly, policy tools to control land take and to limit the negative impacts require particular examination, as they may be numerous and may converge from or diverge toward each other or other public policy instruments.

To answer these questions, IFSTTAR and INRA applied the classic principles of an ESCo scheme (DEPE, 2018), which is based on international scientific references relating to the various aspects of the issues. As a result, certain phenomena, and in particular recent ones, cannot be precisely assessed, either because of the lack of published work, or because the available studies have been conducted in contexts too far removed from the conditions observed in France. This ESCo also faced an unusual difficulty due to the polysemy of the term ‘soil artificialization’. Soil artificialization (‘Land take’ in English) as it is understood in France (and in Europe) is essentially a statistical concept used in particular in the CORINE Land Cover database (CLC), but inconsistency between the different scientific disciplines used for this review revealed that the concepts of urbanization or soil sealing were often preferred. However, these three concepts, although they partly overlap, are not exactly synonymous, which, while contributing to the richness of the work, has increased its complexity. Therefore, the literature review component of this expert summary required many adjustments and several combinations of key words so that each discipline, approaching the phenomenon through different concepts, could contribute on a firm conceptual footing. In addition, the experts have, according to their disciplines, made important additions.

Fifty-five French-speaking experts from various institutions (IFSTTAR, INRA, CNRS, Université de Saint-Etienne, Paris-1, Brest, Montréal, etc.) contributed to this study. Some coordinated components of the review and participated in the integration of different perspectives and disciplines, while others contributed more specifically to the chapter(s) relating to their particular area of expertise. Given the multidisciplinary nature of the issues surrounding land take, the expertise of the experts is varied: they come from economics, geography, ecology, pedology, hydrology, agronomy, law, etc. (see list at the end of this publication).

The results of this study are supported by a bibliography of more than 2,500 references, assembled by two scientific and technical information professionals (INRA and IFSTTAR). This is composed mainly of scientific articles to which some statistical data, books and technical reports have been added. The experts extracted and assembled the relevant elements to clarify the questions.

The ESCo provides neither advice nor recommendation, and is not intended to provide operational responses to questions posed by managers. It carries out a summary of the state of knowledge – as complete as possible – of the determinants and impacts related to land take in France and attempts to identify policy tools through a multidisciplinary approach combining life sciences and economic sciences. It highlights the specific problems associated with this phenomenon. The research organisations, IFSTTAR and INRA, are committed to the terms and conditions under which the expert report was conducted: quality of the documentary work, up-to-date bibliographical sources, transparency of the discussions between the experts, management of the working group and drafting of the synthesis and communication documents in a form that reconciles scientific rigour and readability by a wider public.

‘Land Take’, an ambiguous scientific concept

The statistical measurement of this concept remains uncertain …

The concepts of ‘artificialized land’ refer to specific land use and land use changes, respectively. They were initially introduced by agronomists who sought to understand the changes in the French landscape by identifying the various land uses and their changes (Slak and Vidal, 1995a). The approach was intended to support the theory that changes in agriculture ‘have shaped the rural landscape’ and to investigate the causes of loss of agricultural land (Slak and Vidal, 1995b). In statistical terms, this approach has led to the distinction of four major types of land use: agricultural, forestry, spaces considered ‘natural’, and the balance, known as ‘artificialized land’. The term ‘land take’ was thus constructed to designate the conversion of surfaces from a natural state (wasteland, natural grassland, wetland, etc.), or from forestry or agricultural uses. These definitions are therefore a negative construct, and cover a wide range of uses and cover types, with potentially varied determinants and impacts. These include built and unbuilt spaces that have the common characteristic of being strongly shaped by human activity (housing, industrial buildings, office buildings, construction sites, quarries, mines, dumps, etc.). Green spaces associated with these uses (parks and gardens, sports and leisure facilities, etc.) are also considered to be artificialized land.

Despite the (relative) simplicity of identifying ‘artificialized land’ in principle (everything that is not agricultural, forestry or ‘natural’), there are significant discrepancies between the estimates from the main statistical sources. According to the Ministry of Agriculture (Teruti-Lucas method), 9.3% of French soils were classified in 2014 as ‘artificial land’, while the European source, favoured by the Ministry of the Environment (CORINE Land Cover estimate), estimates this share at 5.3% in 2012. As will be discussed, these differences can be explained relatively easily by the characteristics of the methods and techniques used to identify land use. Nevertheless, the magnitude of the discrepancies, combined with classifications within non-overlapping categories, makes land take data difficult to interpret when analysing the causes of and prioritizing responses to land take.

… but is increasingly used in the public debate

Despite its statistical uncertainty, the concept of ‘land take’ has flourished in public debate and political discourse. Due to the degree of disturbance that human activities cause to these areas and their environment and because of their ongoing extension, most often at the expense of agricultural lands, land take is seen today as one of the main causes of biodiversity loss. Since 2015, it has been one of the ten 'new wealth indicators' established by the Government Information Service (SIG), following the work of the Stiglitz Commission (2009): it is included alongside growth indicators, employment, human capital, social inequality, etc., as one of the two indicators of environmental impact of French society (as well as the carbon footprint, as measured by greenhouse gas emissions). It was already recognised as an issue in the National Biodiversity Strategy 2011-2020 and was part of the seven indicators proposed in 2014 by France-Strategy to measure the 'quality of growth' (Ducos and Barreau, 2014). It is natural that this concern was therefore expressed in the plan of action issued in 2017 by the Prime Minister to his then Minister for Ecological and Solidarity Transition. In it, Nicolas Hulot was asked to make 'proposals before mid-2018 to combat soil artificialization and soil depletion, which form one of the main threats to biodiversity'. In keeping with this approach, the Biodiversity Plan published in July 2018 includes the objective of achieving a 'zero net artificialization' rate for land by 2050, and the Government is currently working on methods for its implementation[1].

The importance of the issue of land take is usually justified in the public debate by statements such as 'artificial land generates a loss of land resources for agricultural use and natural areas', which infer that its role in the degradation of biodiversity and in the loss of agricultural land should be considered together. This dual-faceted objective is ambiguous, however, as the preservation of agricultural land and biodiversity are not necessarily convergent. It is legitimate to seek to limit the environmental impacts of land take, as with all human activities, but this objective does not necessarily and exclusively involve controlling the extension of these types of use.

Nevertheless, its prominence in the public debate and the importance that underlies it, combined with the difficulties of defining land take, obliges us to attempt to clarify the scope of this concept and to examine the issues it encompasses. Indeed, artificialization implicitly or explicitly refers to two other concepts: waterproofing and urbanization. Neither of these two concepts, although closer to the concepts used by scientists, covers all the components that the overarching statistical definition seeks to integrate.

Is the sealing of surfaces synonymous with land take?

As all soils in artificialized lands have undergone strong disturbances of their biophysical characteristics by the extraction or addition of material (often mineral), mixing of different soil horizons, changes in the nature of their cover, etc., it is fundamentally the soil, as a natural environment, that will be affected by the change of use. Its structure, chemistry and biology are modified to varying degrees. These modifications, associated with the activities that develop on these soils (which soil scientists classify as

1. Plan biodiversité (Biodiversity plan), Axe (Axis) 1.3, July 2018.

SUITMA - *Soils of Urban, Industrial, Traffic and Military Areas*), may impact all aspects of the environment, including biodiversity (terrestrial and aquatic), air, water and the human environment.

However not all artificialized lands undergo a literal 'waterproofing' or 'sealing' of their surface. Significant areas of 'artificialized land' are not covered with a hermetic mineral cover, and are therefore not 'sealed'. Thus, according to the Teruti-Lucas data, and despite the limitations of this data that will be examined in detail later, more than 30% of artificial soils in 2014 were 'artificial grassy soils'. These substantial areas (1.6 Mha) mainly correspond to green spaces, recreation and leisure areas and private gardens associated with individual housing. We can assume that the environmental impacts of areas with these vegetative covers differ substantially from those with 'built land' type covers (less than 1 Mha in 2014) and from the sealed or 'macadamized' portion of the 2.5 Mha of 'coated or stabilized soils' whether they are linear (roads and other transport infrastructure) or non-linear (car parks, building yards, etc.).

This key to the degree of soil sealing or, more generally, the level of disturbance to the soil, is the one favoured by soil scientists and most biologists. Given the effects that each type of cover or disturbance may have, the way in which they combine to form a 'landscape' or a 'landscape mosaic' then constitutes an important key to understanding environmental and other impacts.

Urbanization, a major driver of land take, continues beyond city borders

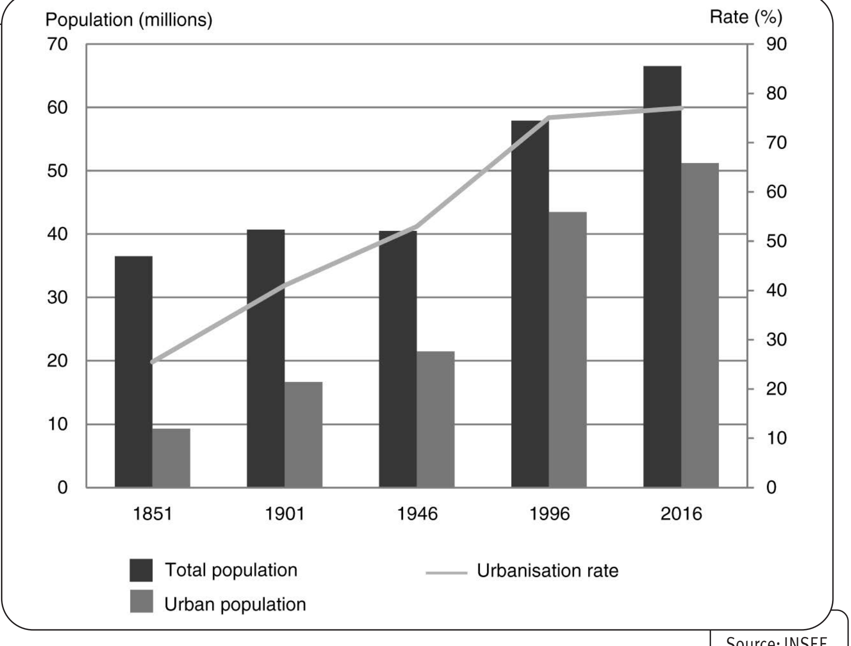
As a major characteristic of contemporary societies, urbanization represents a large component of artificialized land, and is clearly a major driver of land take and related land use changes. Nevertheless, even the CORINE Land Cover inventory, which we will see later fails to include some artificial surfaces in low density areas (i.e., in rural areas), highlights the importance of land take beyond the urban fabric; indeed, it identifies that as of 2012, 75% of artificialized land is located within continuous or discontinuous 'urban fabric' (2.3 M^2 ha), the rest being industrial or commercial areas, road networks, railways, material extraction sites, landfills, construction sites, sports and leisure facilities, etc., which are probably more dispersed through space. Moreover, contemporary urban dynamics, which include urban concentration, urban sprawl and peri-urban development have led to a rethinking of the links between urbanization and land take.

Urbanization, an unavoidable social phenomenon

Across the history of humankind, urbanization is a recent but inevitable phenomenon. The rate of urbanization among the global population has just passed 50%, while in France almost 80% of the population now lives in a city or 'urban unit' (Fig. 1), a level comparable to that of other industrialized countries. For some European countries, such as Belgium and

Denmark, the rate is close to 90 per cent. No developed country today has escaped urbanization, regardless of its political or economic system, and all emerging and developing countries are now seeing their urban population and their rate of urbanization rapidly increasing. The link between urbanization and development, usually measured by the long-term growth of real gross domestic product (GDP) per capita, is largely accepted. Historically, increases in agricultural productivity and the consequent emergence of agricultural surpluses allowed cities to develop. People who were able to exit agricultural economies established themselves at the conjunction of communication routes (usually fluvial) and agricultural areas that were sufficiently productive to create the food surpluses required by the city. With the advent of the industrial revolution, the circular and cumulative causation underlying the mechanisms of contemporary urbanization were set in motion. Economies of scale (within firms), and economies of agglomeration (market and non-market) where companies benefit from by being closer to each other, encourage industrial firms to concentrate geographically, either in existing cities or around the required natural resources. This industrial concentration then attracts workers that, due to productivity gains, are surplus to the agricultural sector. This migration to urban centres in turn increases the size of local markets for goods and services and for labour, thus attracting more firms to join the agglomeration.

Figure 1. Population, urban population and urbanization rates, from 1851 to 2016.



Source: INSEE.

Nevertheless, the agglomeration of populations and economic activities in a small number of locations creates a trade-off, namely the price of land. This increase in land prices most heavily impacts people for whom housing forms a large proportion of their budget. Consequently, cities will tend to spread as their population grows, thus increasing their land consumption and changing their shape.

Europe within the global urbanisation process

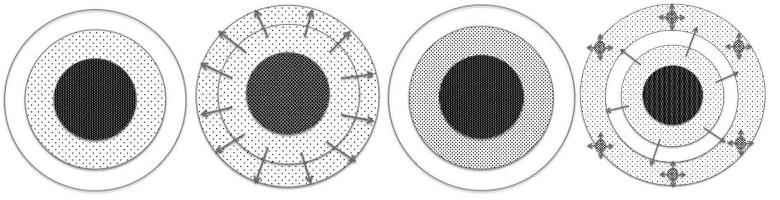
Seen from a global perspective, Europe is a region of small towns, separated by an average of fifteen kilometres. Almost half of the population lives in urban areas of less than 500,000 inhabitants, which clearly differentiates Europe from other continents. As a corollary, the share of the population living in large cities with more than 5 million inhabitants is quite small (less than 5% against 10 to 15% in other regions of the world with comparable urbanization rates). Although Paris belongs to the category of megacities in size, neither France nor Europe is required to manage massive concentrations of people such as those that have developed or are developing in the North-eastern US, Japan, or in the Chinese deltas.

Europe is also distinguished by its average urban densities: compared to other continents, they are in an intermediate position between the extreme dilution of North American cities and dense Asian cities. Broadly, the average urban densities are approximately 2,000 inhabitants per km^2 for North American cities, 10,000 to 40,000 inhabitants/km^2 for Asian cities, and 4,000 inhabitants/km^2 for European cities.

Urban sprawl, a corollary of metropolization

Urban sprawl occurs according to two contradictory processes depending on the geographical scale of observation. At the national or continental level, metropolization attracts a concentration of social and productive assets to the largest cities. At the local level, however, the dominant trend is to spread, due to the increasing land prices that result from this concentration. Two major forms of urban sprawl can be distinguished. In the first, the city extends by expanding its own urban boundaries, with new urban development adjacent to pre-existing city developments. The second is discontinuous, with populations or companies moving to villages close enough to the city to commute for work, but far enough to remain separate from the city (Fig. 2). It is this dual phenomenon of urban sprawl that, in France, led INSEE to develop its Zoning into Urban Areas (ZAU) in addition to its distinction between urban units and rural municipalities (Brutel and Levy, 2011). On the basis of home-to-work mobility and its orientation, it is possible to distinguish between different municipalities that are influenced to a greater or lesser extent by the urban centres (Fig. 3). In the second instance, the continuation of the metropolization trend may also lead to an extension of urban sprawl around secondary peripheral centres that were formerly 'autonomous' (Fig. 2).

Figure 2. Illustration of the phenomenon of 'Leapfrog', literally 'to exceed' in French, which schematizes the forms of urban sprawl.



Grey scales, from darkest to lightest, correspond to the density of the population, from the highest to the lowest. 1: Pre-growth; 2: Growth by urban extension; 3: Growth by densification of the periphery; 4: Growth by expansion of secondary towns.
© Gilli, 2017.

The first form of urban sprawl thus increases the surface area of the city and extends its borders: the artificialization of the land that occurs there is clearly part of urbanisation. The second densifies peripheral areas which, without becoming urban, do not remain rural but become peri-urban. In this case, the resulting artificialization of the land is closely linked to the urbanisation process but takes place in municipalities outside the city (regarded as a continuous built environment).

This process of urban sprawl by peri-urbanisation took place in France and Europe at a relatively late date (the 1960s). It appears to be slowing down, the peak of the movement having occurred before the 2000s. Over a period of some thirty years, between the early 1970s and the end of the 20th century, it transformed the demographic balance between urban and peri-urban areas, as well as the French landscape, particularly the peri-urban landscapes. The territory now under urban influence covers a large part of the national territory (only 7,400 of the 36,700 French towns are excluded) and contains 95% of the metropolitan population (Fig. 3). While nearly 50 million French people live today in a centre, almost 22 million live in a peri-urban municipality, most often under the influence of one (or more) of the 241 large urban centres. The difference in population density between the centres and the crowns to which they extend, is significant: of 820 inhabitants/km² in the large urban centres, the population density drops to 72 inhabitants/km² in the suburbs around these same centres, probably leading to different issues regarding the land take that occurs there.

Initially driven by populations seeking residence outside the cities while continuing to work in them, the urban sprawl gradually spread to companies (first commercial, then logistical, then industrial) that today tend to reposition their new establishments in peri-urban areas.

In addition, a dense network of transport infrastructure (rail and road) has developed between cities and within their areas, aimed both at improving access to peri-urban areas and improving interurban links. The resulting land take thus also affects more distant rural areas (i.e. not peri-urban), and then becomes linked with other types of land take such as tourist and leisure activities, second homes, and industrial and commercial enterprises that are subsequently attracted to these areas.

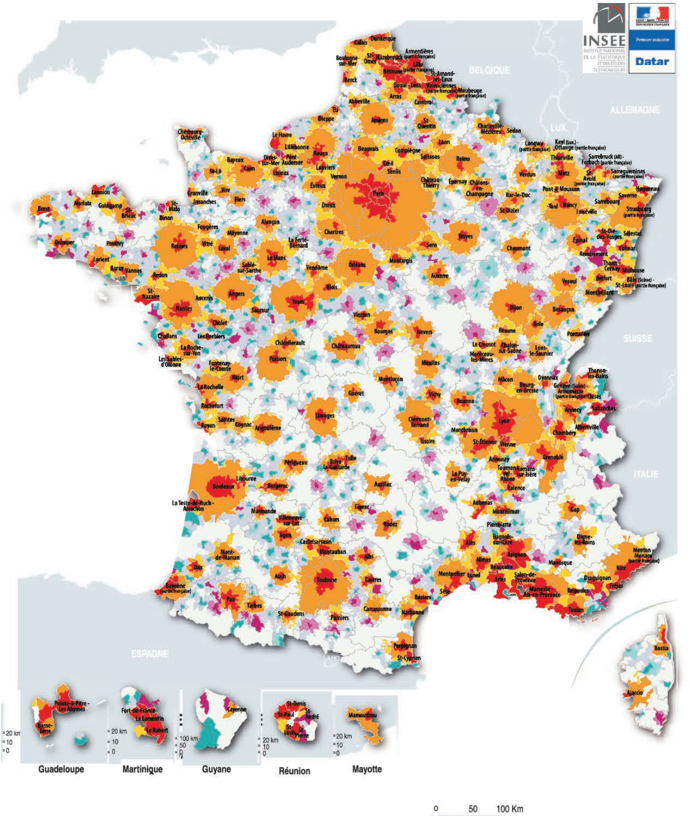
Thus, land take cannot be reduced either to the waterproofing of part of the soil or to urbanisation in the strict sense of the term. Neither of these two approximations makes it possible to take into account all the dimensions covered by the statistical definition of this concept. Its components are multiple and complex; consequently, so will be the analysis of its causes and consequences. To try to understand this clearly, it appears necessary to have an analytical framework that can serve as a basis for interpreting scientific results, or for repositioning them in the specific French context(s). From the above analysis, it emerges that the causes and consequences of land take, and the measures that could limit its negative impacts and/or its extension, must be understood according to the following three major dimensions:

• the nature of the disturbances and the ground cover after its ‘artificialization’ (waterproofing, mineralization, plant cover, etc.) combined with the way in which a given surface fits in with local artificial surfaces of different cover, i.e. the landscape mosaic of which it fits;
• its positioning in the urban fabric (centres of dense cities, suburbs, zones extending the city's borders, peri-urban municipalities, municipalities beyond urban influences);
• the type of activities that take place at the location (individual or collective housing, industrial activities and their nature, tertiary activities, commercial and logistical activities, transport infrastructure, etc.).

It is from the simultaneous consideration of these three dimensions that the following scientific results must be understood. Furthermore, in order to evaluate the impacts of the change of land use towards artificialization, it is necessary to take into account the characteristics of the soil before its artificialization.

In order to be more closely aligned with the framework of the current debate on land take, this synthesis has been structured in a way that is strongly oriented towards the issues at stake. After a critical examination of the methods of measurement of land take and the results obtained in the French context (Chapter 1), we will begin by focusing on its environmental impacts, while trying to limit ourselves to the most direct effects on the environment. Since artificialized land supports all economic and social (non-agricultural and non-forest) activities, it is necessary to avoid attributing to the artificialization of soils *all* the impacts of *all* human activities (non-agricultural and non-forest) of which these soils are simply a medium. An initial focus will be on the very direct effects of artificialization on the soils themselves, both in terms of their physicochemical properties and their biology (Chapter 2). Attention will then extend to the impacts of artificialization on their environment, successively addressing the direct effects on terrestrial biodiversity, landscape fragmentation and urban hydrology, and then some of the indirect effects

Figure 3. Urban zones according to INSEE, 2010.



- Major centres - 3,257 municipalities
- Crowns of the major centres - 12,305 communes
- Multopolarized municipalities of large urban areas – 3,980 municipalities
- Laval — Names of major urban areas
- Medium-sized centres - 447 municipalities
- Crowns of medium-sized centres - 803 municipalities
- Small centres - 873 municipalities
- Crowns of small centres - 587 municipalities
- Other multipolarized communes
- Isolated municipalities, not influenced by centres

© INSEE - DATAR - IGN, 2011. Production: DATAR – Observatoire des territoires (Territorial Observatory), 2011.

on the urban climate and atmospheric pollution (Chapter 3). The consideration of these few indirect effects, which is included in the ESCo's terms of reference, is included as a way to explore some of the negative effects of urbanization that households may seek to avoid by 'peri-urbanizing', thus accentuating land-use changes in peri-urban areas. Particular attention will be given to the direct and specific effects of land take on the agricultural sector and activity, especially in urban fringes and peri-urban areas: loss of agricultural land, reduction of productive capacity, land pressure and conditions for agricultural activity (Chapter 4). The economic and social determinants and impacts of land take will be examined in a second step, and will be organized around household residential location strategies and the resulting demand for housing construction (Chapter 5), followed by strategies for locating economic activities with two specific illustrations: one relating to the construction of warehouses and logistics platforms; the other to transport infrastructure (Chapter 6). Finally, the responses that public policies can make to land take are discussed (Chapter 7).

1. Methods of measuring the extent of land take in France

Given the differences from one French source to another regarding the extent of artificial surfaces and their recent changes, it is necessary to review both the approaches and methods that are used, and the way in which they are employed as public statistics, in order to understand their uncertainties and limitations. It is on this basis that we can understand the discrepancies found between sources at the French level and be able to analyse the amount and nature of artificialized soils and trends in the progression of land take in France, while placing these trends in a European context. That said, and despite differences in the assessment of the rate of land take, all sources point to the conclusion that there is a trend towards increased land take, both in France and in Europe.

Objectives and methods for measuring land use change

None of the methods used to identify and measure artificialized land and land take are directly aimed at this single objective. All of them are, by their very nature, intended to cover the whole of a territory and to examine the different types of land use that comprise it, and the changes in land use. It is therefore by adapting the categorisation of land uses that their artificialization can be identified, which will appear as a typology of land use categories, itself made up of possible sub-categories. These methods for analysing land use, with their ability to identify artificial soils, are the focus of this study, after having specified the subjects that more particularly concern land take.

Objectives of the measure

The measured 'objects' are associated with several spatial scales that focus on several types of elements ranging from the building to the parcel, the island, the neighbourhood, the agglomeration or even the urban footprint. The measurement of land take refers to three things: surfaces, the urban footprint and land use change.

Surfaces

By definition, artificial surfaces are areas removed from their 'natural' forest or agricultural state, whether they are built, paved or not. They include built land used for residential use or for industrial or commercial use (offices, factories, etc.), paved or stabilized land (roads, railways, parking areas, roundabouts, etc.), and other areas not built but strongly disturbed by human activity (construction sites, quarries, mines, dumps, etc.). This category also includes artificial green spaces (urban parks and gardens, sports and leisure facilities, etc.). Artificialized surfaces are distinguished from each other by their degree of waterproofing and the nature of the disturbances that their soils have undergone.

It should be noted, however, that some so-called non artificial areas may be completely impermeable and some so-called artificial areas may be completely permeable.

The urban footprint

The urban footprint designates the outline of urban expansion. The broad use of this concept, particularly in approaches that use remote sensing, is explained by its ease of calculation, often based on free Landsat images. Thanks to the availability of high-resolution SPOT images with a panchromatic sensor with 10 m resolution, the limit of this urban footprint has been the subject of a series of analyses in order to better reconcile the statistical and satellite definitions. The urban footprint – a term with a negative connotation, but which refers to the technique of image processing where a greyish spot is perceived – is a major component of land cover and an indicator of land use. It is an important variable in many urban and environmental studies.

The urban footprint does not describe the totality of artificialization since it focuses on the urbanised space, and omits, for example, the extensive transport infrastructure that connects urban areas.

Land use change, artificialization

Artificialization considers the modification of initial surfaces to artificialized spaces (transformed for non-agricultural uses) over a given time step. Several elements can be observed: the location, the type and the pace of these changes. Relatively few examples in the scientific literature involve a comparison of three or more dates, which would allow closer observation of trajectories and growth rates. The limits of such approaches are as much methodological as technical and financial, although the recent free availability of archived images has led to greater interest in time series studies.

Methods of measurement

Among the various methods that can be used to identify artificialized land and to study land take, the processing of satellite images is widely used. Although remote sensing methods are not created primarily for the measurement of artificialization, they produce data on a European and global scale, and contribute to the understanding of land use. In France, the methods and data used to measure land take within the territory vary according to the scale of implementation (national, regional, local), the scale of objects (from the parcel level to the national level) and the objectives (monitoring exclusive of land take, land use map, aggregation of statistics).

Across the variety of approaches, the measurement of land take is rarely the primary purpose of the method or data used. It is therefore often a question of adapting tools, data and methods to a concept that is still undefined, or of extrapolating information.

Remote sensing methods: diversity, benefits and limitations

Remote sensing data

Most studies that measure urbanization, soil sealing or land-use change by remote sensing have used imagery from the Landsat series (MSS, TM, ETM +, OLI). There is no single product designed to measure land take, and the choice depends on the adequacy of the characteristics of the available images (spatial, temporal, radiometric and spectral resolutions, temporal depth, etc.) to the desired objectives (characterization of surface type or urban footprint, evaluation of change). Remote sensing research using medium resolution images tends to overestimate the impervious surfaces, and the results cannot be used on analyses at a more local scale due to the overly coarse spatial resolution of these images

There are three main types of image processing methods: those related to optical sensors and radars, those related to very high spatial resolution (VHR) sensors, and multi-source and multi-image image fusion methods between different resolutions. Radar is useful for detecting the land in cloudy zones. Sensors with very high spatial resolutions make it possible to precisely quantify the density of buildings, the interface between them and the natural environment, or the shapes of buildings in relation to their uses. Some data collected in this way make it possible to obtain building heights and thus measure the densification of urban areas. Finally, image fusion methods make it possible to simultaneously exploit images from different sensors. Lidar active remote sensing technology can also estimate the height of buildings and thus urban densification.

Methods of processing satellite images

Classification methods. Classification allows pixels to be categorised into classes according to certain rules. Classification is often multi-spectral, with some methods said to be supervised because they use upstream learning methods such as Maximum Likelihood (ML), *Support Vector Machine* (SVM) or Minimum Distance. Unsupervised methods are used more rarely (ISODATA or KMEANS). To accompany these classifications and to complete the interpretation of the results, various indices are calculated. These include vegetation, brightness, building, soil moisture, morphological or landscape indices, among others. Other spatial data such as digital elevation models, geographical reference data, or aerial photography are often used to enhance or validate results locally.

Object oriented methods. Since the 2000s, the scientific community has moved towards classification methods, where the units to be classified are not simply pixels in the image, but groups of pixels that can be described not only by their spectral reflectance, but also by their texture and geometry. These approaches, grouped under the name of Object Oriented Methods are increasingly used with VHR images. They have also recently been applied to medium and high spatial resolution images such as Landsat, IRS, RapidEye and SPOT, to extract urban surfaces in countries with strong urban dynamics, such as India, China or the United States.

Advanced methods. Approaches such as Neural Networks or Cellular Automata allow the integration of expert knowledge to better characterize geographic areas. The development of synthetic indices resulting from the combination of reflectance measures in the visible and infrared spectra (indices of vegetation, brightness, buildings, soil moisture) has led some authors to also perform stepwise classifications by means of the thresholding of each of the indices in order to gradually control the discrimination of the various surface types (bare soils, water, natural or cultivated vegetation, buildings, etc.) that they sought to recognize. This type of approach is grouped under the name 'decision tree'.

After identifying the built surfaces on images, some studies seek to characterise and quantify the spatial organisation of the built environment along with their spatio-temporal evolution (densification, spreading, etc.), using textural analysis or methods based on Landscape Ecology.

Image interpretation of satellite or aerial images

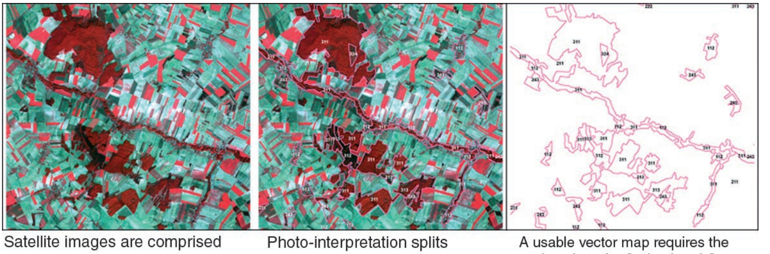
Image interpretation involves asking experts to derive the nature of land use through image media and their knowledge of the field. The images are first rectified and put into a projection system (orthoimage), and the image is then interpreted. A typical example is the creation of the CLC (*CORINE Land Cover*) database at the European level.

CORINE Land Cover is a European database of biophysical land use. This project is led by the European Environment Agency and covers 39 states. The CORINE Land Cover inventory and the high-resolution thematic land-use layers are pan-European geographic databases, made available by the Territorial Service of the Earth observation program Copernicus. In France, the *Service de l'Observation et des Statistiques* (SOeS), within the Ministry of Ecological and Solidarity Transition, is responsible for its implementation. This vector database, which includes four versions (1990, 2000, 2006 and 2012), is produced by human image interpretation of satellite images (Landsat, SPOT, IRS, etc.) with a geometric accuracy of 20 to 25 m (Fig. 1.1).

CLC focuses on the biophysical occupation of the land rather than its use, by classifying the nature of the objects (crops, forests, water surfaces etc.) rather than their socio-economic function. It is divided into three levels, with 44 categories at Level 3, 15 categories at Level 2 and 5 categories at Level 1. At Level 1, Category 1 describes artificialized land. It contains: urbanised areas (continuous urban areas and discontinuous urban areas), industrial and commercial zones and communication networks (road and rail networks and associated spaces, port areas, airports), mines, landfills and construction sites (material extraction, landfills and construction sites), and non-agricultural artificial green spaces (urban green spaces, sports and leisure facilities). The CLC data is therefore aimed at a detailed understanding of land take.

The complete database divides the territory into polygons of more than 25 hectares, each of which is assigned a code from the nomenclature, and the change databases map any changes of more than 5 hectares between two dates. Each change polygon contains the initial and final land cover code. CLC offers a free database with temporal depth and European coverage accessible in vector format. On the other hand, the thresholds that are used are high, which, in spite of their regular improvement, limits the spatial precision, in particular in sparsely-populated areas.

Figure 1.1. Schematic diagram of image interpretation.



Satellite images are comprised of pixels, each of which is a 'colour'. Photo-interpretation splits the land into polygons. A usable vector map requires the assignation of a Corine Land Cover code to each polygon.

Statistical field surveys

These statistical surveys are based on direct field observation of land use from a defined number of observation plots. Therefore, the sample plots on which these surveys are carried out must be defined (Box 1.1). The results are then extrapolated over a larger area. Like the previously-described methods, these surveys are not primarily intended to measure land take, but to determine the land use.

The advantage of these methods is that sampling makes it possible to reduce costs and carry out regular surveys to study the evolution of a phenomenon (in this case, land cover). Another advantage concerns the small size of the observation unit, which makes it possible to report cover - and changes in cover - of areas that are poorly or barely detected by remote sensing. The disadvantage is that extrapolation may be questionable when the population is heterogeneous, as is the case for metropolitan land use. Sampling may be questionable in terms of the distribution of points, their number and spacing as well as the extent of the observation unit, particularly when the phenomena to be measured extend over small areas (as may be the case with artificialization in certain areas). Moreover, this type of method is more sensitive to interpretation bias on the part of the observer than the previous ones: they require a highly structured protocol and well-trained personnel to ensure consistency of results, especially when the data are difficult to interpret.

Box 1.1. The Teruti-Lucas Field Survey in France

The survey is based on a sample, in mainland France, of about 300 000 observation plots (3 m diameter extended to 40 m in case of heterogeneous natural occupation), distributed in 30,000 clusters (or segments) approximately, 6 km apart (3 km in Ile-de-France, 2 km in overseas territories). Each cluster (size 1.5 km x 600 m to 1.5 km x 1.5 km) generally comprises 10 plots (25 in overseas territories and Ile-de-France), 300 m apart. The plots are all geolocated, but their coordinates are not accessible for reasons of confidentiality. Each year, about 700 field investigators are recruited, trained and managed by the Regional Statistical and Economic Information Service (SRISE) between May and July to observe and characterize 185,000 plots, according to a collection nomenclature consisting of 122 land cover types and 38 different land uses. Methods have been regularly improved to try to correct sampling defects[2].

The value-adding to administrative files and databases

Land files are directly derived from the fiscal cadastre covering the national territory. The *Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement* (CEREMA), which formats and disseminates them on behalf of the Ministry in charge of the environment, has implemented a method to determine annual changes of natural, agricultural and artificial spaces between 2006 and 2015 at the plot scale but communicated at a local government scale. The land market data of SAFER (*Société d'Aménagement Foncier d'Etablissement Rural*) provide information on the transfer of agricultural land to non-agricultural uses, which is usually part of the land take process.

The new generation of vector cadastral data provides almost complete coverage of the contours of parcels and built-up polygons (data from the IGN's PCI and BD Parcellaire® digital cadastral plans). This data is available annually and covers the country piece by piece. Most of the geomatics services of local authorities interested in the measurement of urban sprawl improve on the layers from the standard CLC satellite data, using these datasets to better evaluate and qualify the consumption of space for urbanization[3], and supplementing them with IGN BDTopo® data to map infrastructure. This data can be linked to the State Land Files (MAJIC files[4]), which contain very detailed information regarding the owners of land and property, as well as the characteristics of built properties and

2. For an analysis of this method, see Virely 2017.
3. Roads, as with scattered buildings, are difficult to spot with remote sensing without very high resolution. Vector data from the IGN's BD Topo® provide one of the main sources of complementary data to include this type of land take and are frequently used by the urban planning departments of local authorities for the improvement of MOS.
4. They are also referred to as land documentation or literal documentation of the cadastre.

parcels. These land files are part of the usual repository of municipalities and their groupings for the management of urban planning and for the management of non-collective sewerage facilities. Today, they can use CEREMA's cadastral files when they do not have a land use mode (MOS).

The strategy of relying on several temporal versions of the PCI allows an error rate below 0.01% (Urbansimul project). Coupling these two sources of data makes it possible to distinguish the types of building between dwellings and professional premises, to characterise the types of property and owners that are the central drivers of land take processes. They also allow us to distinguish between hard and light construction, which can be very useful with regard to the reversibility of constructions. Other recent vector sources, such as urban planning documents in the CNIG/Covadis format at 1/5000 scale, make it possible to qualify the constructible nature of the plots and to know the precise rules of constructability in force. These documents cover the French territory in a very heterogeneous way, but have developed very quickly (in the Provence-Alpes-Côte d'Azur region in 2017, over 50% of municipalities were covered).

The combined use of such data makes it possible to analyse the process of land take at the level of the spatial unit at which decisions are made, i.e. the parcel or group of parcels, while including the main descriptors of the properties and owners, and allowing analysis of the interactions with urban zoning plans and the land and property market.

Approaches by retrospective or predictive modelling

The predictive modelling of land take is a recent and growing practice designed to inform decision-makers about the possible impacts in terms of space consumption, future forms of urban sprawl and its socio-economic and environmental consequences given specific strategies or in the absence of medium or long-term planning strategies. Analyses of past (retrospective) changes are a prerequisite for exploring future urbanization using spatial simulation models. Once they are calibrated, model validation is performed by simulating urbanization over a past period and comparing the results from the simulation with the situation observed for the same date. Most studies have a predictive outlook of 20 to 30 years though, more rarely, distant horizons such as 2100. Others are more predictive and aim to identify areas where urbanization is likely to occur in the short term. These models can integrate complementary data such as future transport networks or reflect planning strategies to produce more or less contrasting scenarios. As data availability is not always certain, particularly in the case of socio-economic data, there is a relatively systematic resort to geographical data (distance to road networks, topography, etc.).

The benefit of this type of approach lies in the production of maps for estimating the impacts of artificialization on urban climate, runoff, green belts, etc. Modelling is also used as a means of understanding the determinants of land take. Almost all of these studies use a simplified nomenclature of land take, where urban is considered as a single class of land use. It should be noted that the practical application of prospective modelling is still in its infancy and there remain a number of unresolved issues.

Measurements and trends in land take in France

STUDIES CONCERNING THE ANALYSIS OF CHANGES IN LAND-USE urban or other types of land take reflect the global trend towards artificialization. This land take has been to the detriment of various types of land use: agricultural or vegetated land, forests, and natural or unused areas, and has enabled cities to develop. While some studies focus on the boundary of urban areas, most analyse land use change over time more precisely to explain specific transitions. These very different estimates show that the trends in land take are nevertheless consistent, and place France around the average among European countries.

The different approaches to measuring land take in France

Table 1.1 summarizes the essential characteristics and properties of the main sources of data that, in France, can help to understand the level of land take at a national level. Despite their profound differences in approach, the first two (CLC and Teruti-Lucas) make it possible to identify the issue from an analysis of the breakdown of the various land uses over the entire territory. The land files, especially from the cadastre, are more directly focused on private property, built or undeveloped: they ignore public land and transport infrastructure. Surveys of the structure of farms focus on the contraction of the territory dedicated to agricultural production and offer only an indirect analysis of land take. Finally, the SAFER data, which records the agricultural areas that could be transformed into building surfaces, focuses on the loss of agricultural areas more directly attributable to urban development.

Table 1.1. Comparison of different tools for measuring land take in France

Name of the tool	*CORINE Land Cover*	Teruti and Teruti-Lucas	Land files	Ministry of Food and Agriculture (MFA) census	SAFER (Land Development and Rural Establishment Companies) land market
Methodology	Visual interpretation of satellite images (+ additional data)	Extrapolated point surveys (+ PAC data since 2012)	Cadastral map + information on built and unbuilt properties. MAJIC data	Survey of Utilised Agricultural Areas (SAU) and Farm Structure (ESEA)	Declarations of intent to convert and transfer, SAFER
Origin / custodian / data accessibility	SOeS - Commissioner-General for Sustainable Development. Open access	Office of Statistics and Prospective analysis - MAA Open access	Direction générale de la Finance publique (DGFiP) / CEREMA Conditional access	MAA Access ?	SAFER Access ?

Table 1.1. Next

Name of the tool	*CORINE Land Cover*	Teruti and Teruti-Lucas	Land files	Ministry of Food and Agriculture (MFA) census	SAFER (Land Development and Rural Establishment Companies) land market
Spatial resolution	25 ha/100 m (5 ha for changes) homogeneous occupation	Statistical data: 309,000 points (3-40 m^2) grouped into 31,500 clusters Not accurate on a scale smaller than the department	Cadastral parcels	Agricultural exploitation	Cadastral
National coverage (% of territory)	100%	100% integrated by administrative units) with confidence intervals	100% outside public land and non-cadastral infrastructure	Agricultural land	100%
History and time step of data	Approx. every 6 years since 1990	Annual since 1982 (coordinated with European 'Lucas' since 1995)	Annual	10 years	Annual Report
Classification	3 hierarchical levels with 44 categories at the finest level	57 categories combining occupation and land use	13 categories	Agriculture	Areas likely to be urbanised, estimated from land markets for areas for urbanization, houses in the countryside and residential and recreational areas
Waterproofing	Yes, for 2012 with CLC HR (high resolution)	Yes, by interpretation	No	No	No

Table 1.1. Next

Name of the tool	*CORINE Land Cover*	Teruti and Teruti-Lucas	Land files	Ministry of Food and Agriculture (MFA) census	SAFER (Land Development and Rural Establishment Companies) land market
Limitations	Low spatial resolution: according to CLC, a third of the municipalities do not have built-up areas	Spatial extrapolation: not mappable. Investigator bias Designed for agriculture: not very accurate for poorly represented classes		Low spatial accuracy (location of a holding's admin. centre)	Data not validated, does not take into account non-market changes in indicating trends
Potential development of the method	Improved resolution with CLC-HR *soil sealing*	Increase in the number of points			
Application	Good mapping (1 :100K, raster 100 m) Possible European comparisons (38 countries)	Progression of land take in France in annual time steps Statistics (no mapping) European triennial comparisons possible (Lucas Eurostat)		Utilized agricultural area (SAU) by agricultural holdings	
Average rate of increase of artificial surfaces per year	33,000 ha / year from 2000 to 2006 16,000 ha / year from 2006 to 2012 (corrections *posteriori*)	61,200 ha / year from 2006 to 2014	27,500 ha / year from 2006 to 2015	Difficult to calculate	83,981 ha / year between 2000 and 2012

Very different estimates

As a logical consequence of the multiplicity of definitions, categories, data types, methods of identification, approaches and possible settings, results observed in the same area vary greatly depending on the data source (Table 1.2). Thus, estimates of artificialized areas in France in 2014 vary from 2.35 million hectares according to the JRC (Joint Research Centre) to 5.1 million hectares according to Teruti-Lucas, and 3 million hectares in 2012 according to *CORINE Land Cover*.

Table 1.2. Various estimates of the level of land take in France and its changes

Data source	Total artificialized area (dates differ according to the source)	Average rate of increase of artificialized surfaces per year (periods vary depending on the source)
Teruti-Lucas (source : Agreste, Ministry of Agriculture and Food)*	4.6 Mha in 2006 5.1 Mha in 2014	61,200 ha /year between 2006 and 2014
CORINE Land Cover (source: ministère de l'Environnement, de l'Énergie et de la Mer, MEEM, Commissioner-General for Sustainable Development, CGDD)**	2.5 Mha in 1990 2.7 Mha in 2000 2.9 Mha in 2006 3.0 Mha in 2012	20,000 ha/year between 1990 and 2000 33,000 ha/year between 2000 and 2006 16,000 ha/year between 2006 and 2012
Global Human Settlement Layer (GHSL), Landsat and other complementary data (photo and census data) (source JRC)	1.04 Mha in 1975 1.75 Mha in 1990 2.03 Mha in 2000 2.35 Mha in 2014	47,000 ha/year between 1975 and 1990 28,000 ha/year between 1990 and 2000 23,300 ha/year between 2000 and 2014
Land files: Ministry of the environment*** CEREMA ****	 - -	33,300 ha/year between 2000 and 2010 31,800 ha/year between 2006 and 2010 27,500 ha/year between 2006 and 2015
SAFER land market***		83,981 ha/year between 2000 and 2012

* Agreste, chiffres et données n° 229, mars 2015, L'utilisation du territoire en 2014.
** Update, land use in France, CGDD n° 219, December 2015.
*** Overview of the quantification of national changes in agricultural surfaces, May 2014.
**** The consumption of space and its determinants according to the Direction générale de la Finance publique land files, analysis and inventory as of 1st January 2015, December 2016 (for this method, non-cadastral land is not considered).

These very significant differences arise from the differing objectives, methods and data sources. As a European-wide source derived from the interpretation of remote sensing imagery, there is both interest in and the potential for a very precise analysis of the land use up to very fine scales, although available CORINE Land Cover to date comprises fairly large polygons (25 ha and 100 m wide, and 5 ha for the extensions to artificialized land).

Their shapes and locations are arbitrary because they adapt to the contour of areas identified as homogeneous land use. Although this dataset allows accurate measures of land take in densely-populated and homogeneous areas (from the perspective of both buildings and other waterproofing surfaces), such a level of resolution can underestimate land take in sparsely-populated areas by excluding hamlets, scattered settlements or facilities and narrow road surfaces (Box 1.2). However, it should be noted that the new CLC-HR database (*CORINE Land Cover* - High Resolution) complements the CLC database with additional layers including a waterproofing layer that integrates, among other elements, hamlets under the threshold of 5 ha and additional transport infrastructure. The addition of CLC-HR data and other network vector data would make it possible to approach a finer description of land take

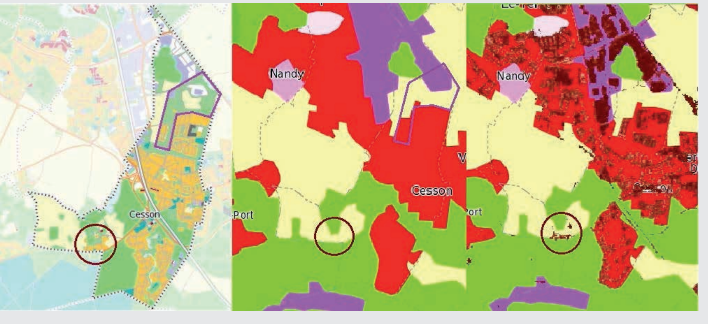
For its part, Teruti-Lucas, the statistical survey of French tenure and land use, suffers from sampling and interpretation biases, which become more significant among less homogenous and scattered surfaces. Therefore, it is well-known that the uses of this source can only be applied at a broader spatial scale (whole territory and administrative regions), with the representativeness of the data becoming lower in smaller areas

Box 1.2. Example of the differences in land cover estimation between MOS and the CLC

Land use (MOS) and CORINE Land Cover (CLC) differ in their estimates, as shown in Fig. 1.2. Here, the red circle encompasses a hamlet present in MOS but absent in CLC probably due to the threshold (25 ha), while the building is seen in the CLC-HR impermeability layer on the right. Furthermore, the area under the purple polygon is classified as 'artificial open space' in the MOS, whereas it is classified as 'arable land' in the CLC.

The spatial thresholds and classification explain the difference in classification between the two data sources

Figure 1.2. Differences between tools for estimating land take: MOS 2012 (left), CLC 2012 (middle) and CLC-HR 2012 (right).



Other sources and methods exist but are applied more locally. This is the case with land use (MOS) measurement by photo-interpretation, particularly in the Île-de-France region. This programme has been inventorying land use patterns since 1982, and its latest edition dates from 2017. Based on aerial photos covering the entire regional territory, the MOS distinguishes agricultural, natural, forest and urban areas (habitat, infrastructure, installations, economic activities, etc.), based on a classification of as many as 81 categories (see below). Using a similar method, the National Institute of Geographic and Forestry Information (IGN) aims to cover the entire metropolitan territory, as part of a research project entitled *Occupation du sol à grande échelle* (OCS GE).

At a local level, the VIGISOL association, in partnership with SAFER of Lower Normandy, has been working since the early 2000s to measure the consumption of space in Normandy. VIGISOL has developed a classification system to define land use before and after urbanisation. The urbanisation process is divided into four main categories: housing, economic activity, communication routes and recreational and sports activities. Those areas for which the land use change was in the process of taking place without it being possible to determine the type of urbanization have been grouped together under the heading 'in the process of urbanization' (margin of error of only 2.5%).

Generally speaking, the harnessing and integration of all available data sources (cadastral data, IGN topographic data, new high-precision satellite images, etc.) could enable a genuine quantum leap towards a more accurate measurement of the level of land take in France.

Consistent land take trends

Despite these differences in estimates, and therefore of the rate of land take in France, all sources are in agreement in that they show an increase in land take over recent decades.

Thus, the four CORINE Land Cover time-slices (1990, 2000, 2006 and 2012) show a 20% growth of artificial surfaces between 1990 and 2012, which breaks down to an increase of 8% between 1990 and 2000, followed by a phase of relative acceleration of the trend (with a growth of 7% between 2000 and 2006) and a slightly slower progression between 2006 and 2012 (+ 3% in six years). This source is particularly well adapted to the analysis of urbanization, and highlights the extension of the urban footprint (continuous or discontinuous) which, in 2012, covers nearly 2.3 million hectares, or 4.1% of the national territory (Table 1.3 and Fig. 1.3). The rate of increase of these urban areas was 2% between 2006 and 2012, although it is not possible to identify their internal composition, in particular whether the amount and arrangement of non-permeable and permeable areas has changed in one direction or in the other. At the same time, the identifiable areas dedicated to industrial or commercial zones, or to more dispersed public installations (because they are outside the urban fabric), have increased over the same period by 8%, reaching nearly 400,000 ha in 2012.

Table 1.3. Breakdown of areas of mainland France by the type of occupancy according to CORINE Land Cover in 2006 (corrected data) and 2012

	2006			2012		
	Millions of hectares	%	%	Millions of hectares	%	%
Continuous urban fabric	0.044	1.5	0.1	0.044	1.5	0.1
Discontinuous urban fabric	2.208	74.8	4.0	2.253	74.3	4.1
Industrial zones, commercial and public installations	0.359	12.2	0.7	0.385	12.7	0.7
Transport infrastructure	0.103	3.5	0.2	0.109	3.6	0.2
Other economic activities	0.098	3.3	0.2	0.098	3.2	0.2
Green spaces and recreational areas	0.141	4.8	0.3	0.143	4.7	0.3
Total artificialized land	**2.953**	**100.0**	**5.4**	**3.032**	**100.0**	**5.5**
Agricultural land	32.696		59.6	32.619		59.5
Forest and natural lands	19.202		35.0	19.192		35.0
Total surface	**54.851**		**100.0**	**54.843**		**100.0**

Source: SOeS, MTES.

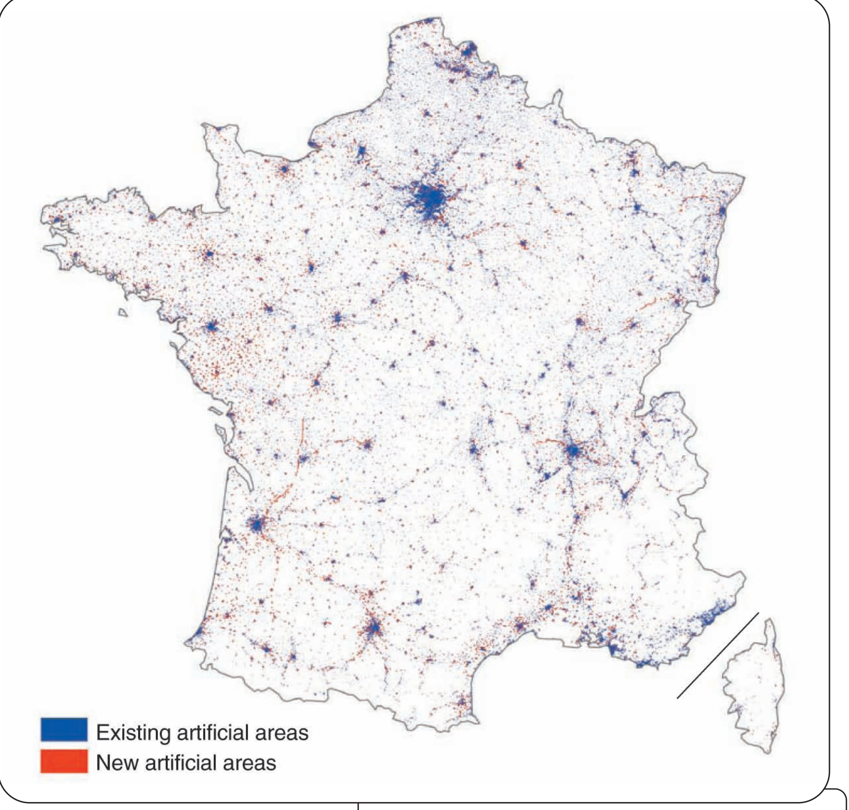
For their part, Teruti and Teruti-Lucas annual data highlight a continuous increase in areas classified as artificialized over the entire period from 1984 to 2014 (Fig. 1.4). After a long period from 1997 to 2006 during which the annual rate of land take remained stable at around 60,000 ha/year, France experienced a significant increase in 2007 (70,000 ha), then a peak in 2008/2009 (> 90,000 ha/year), followed by a decrease in annual artificialized areas until a rebound in 2013 (50,000 ha) which was confirmed in 2014. This annual rate of 50,000 to 80,000 ha/year reflects the reverse flow of farmland losses, which oscillate between -40,000 ha and -100 000 ha/year depending on the year, with 'natural' land being in the intermediate position, losing or gaining area through the years.

The French coastal area represents only 4% of the territory but is home to 10% of the total population, and thus has a density 2.5 times higher than the metropolitan average (285 inhabitants/km^2 in 2010). The population is also increasing more rapidly in this zone, with housing construction pressure three times higher than in the hinterland. The result is greater artificialization: between 2006 and 2012, it grew twice as fast on the coast as inland. In 2012, 14.6% of the territory of coastal municipalities will be artificialized compared to a metropolitan average of 5.5% (*CORINE Land Cover* data)[5]. With the exception

5. These figures are undoubtedly underestimates, and do not fully consider urban sprawl, i.e. diffuse urbanisation, as they are based on CLC mapping at 1/100K scale, and thus only identify features larger than 2.5 ha.

of French Guiana, coastal population density and artificialization are even higher in the overseas departments. However, density and land take decrease rapidly towards the interiors due to rugged terrain or, as in French Guiana, the presence of tropical forest and absence of communication routes.

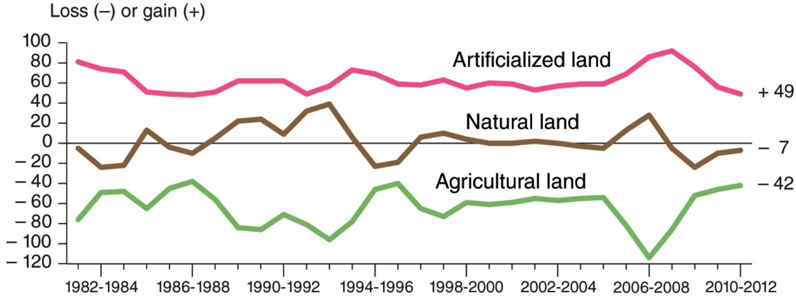
Figure 1.3. Land take between 2006 and 2012, calculated from CLC data.



Polygons representing change have been exaggerated for display.
Source: UE-SOeS, *CORINE Land Cover*, 2012.

This source also allows for an assessment of surface coverage, by making an approximate distinction between impermeable and permeable surfaces (Table. 1.4): in 2014, of the 5.1 million hectares considered in France as artificial, 1 million are built on, 2.5 million ha are paved or stabilized soils, whether linear or non-linear (road or rail infrastructure, municipal roads, car parks, etc.), and the remainder (1.7 million ha) are permeable surfaces (grassed or bare). Over the period 2006-2014, the built-up land has increased to the greatest extent (+ 22%), while coated or stabilized soils have increased by 14%, and artificial or grass-covered soils have increased less than 4%, although we do not know whether these differences in growth rates are related to urban development, urban extension, peri-urban development or land take in rural areas.

Figure 1.4. Trends in the annual increase or decrease in surface area by occupancy from 1983 to 2014, according to Teruti and Teruti-Lucas.



The results are presented as a 2-year running mean.
e.g. 2006-2008 equals the average annual change in surface area between 2006 and 2008.

Table 1.4. Breakdown of the metropolitan area by type of land cover according to the Teruti-Lucas surveys in 2006 and 2014

	2006			2014		
	Millions of hectares	%	%	Millions of hectares	%	%
Built-on land	0.756	16.5	1.4	0.923	18.1	1.7
Coated or stabilized surfaces	2.159	47.3	3.9	2.456	48.1	4.5
non-linear areas	0.719	15.7	1.3	0.841	16.5	1.5
linear areas	1.441	31.5	2.6	1.615	31.6	2.9
Other artificialized lands	1.653	36.2	3.0	1.725	33.8	3.1
Grassed land	1.465	32.1	2.7	1.583	31.0	2.9
Unvegetated land	0.188	4.1	0.3	0.142	2.8	0.3
Total artificialized land	**4.568**	**100.0**	**8.3**	**5.104**	**100.0**	**9.3**
Agricultural land	28.591		52.1	28.029		51.0
Forested land	17.042		31.0	17.033		31.0
Other uses	4.718		8.6	4.752		8.7
Total surface	**54.919**		**100.0**	**54.919**		**100.0**

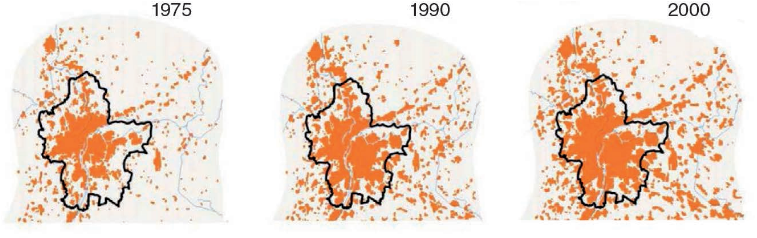
Source: Statistical Service of the Ministry of Agriculture

Land records show a slight increase in the average rate of urbanization for 2015, a trend that SAFER figures confirm for the year 2016. According to their estimates, as in the early 2000s, urban areas account for between 50,000 and 60,000 ha per year (Land Markets Report, FNSAFER 2017).

Overall, the average annual rate of land take within the French territory increased sharply in the 2000s, reaching a peak (2008-2009); it then declined until 2014, before rebounding again in 2015, and continuing in 2016.

Many studies conducted at more local scales are able to provide more refined results. For example, the study on the increase in impermeable surfaces in the Lyon agglomeration carried out by IRSTEA shows significant expansion of these surfaces between 1975 and 2000 (Fig. 1.5).

Figure 1.5. Expansion of impermeable surfaces in the Lyon agglomeration between 1975 and 2000.



Source: Lyon Urban Planning Agency.

Similarly, the study carried out by the *Institut d'aménagement et d'urbanisme d'Île-de-France* on land take in the region provides a description of the changes in different types of surface between 1982 and 2012, as well as analysing the flows between specific categories from 1999 to 2012 (Colsaet, 2017)[6]. It shows a downward trend in the area of agricultural land (- 50,000 ha in 30 years) and the continuous increase of artificial spaces, whether built-up, paved or, to a lesser extent, artificial open space (Table 1.5). After an initial phase of slowing in the growth of artificial surfaces (1999-2008), a clear break occurs between 2008 and 2012, a period during which the slowing down of land take is very pronounced. The rate of growth of built or paved spaces decreases by half, and the artificial open spaces even register a decrease, mainly in house gardens (a long-term trend but which is accelerating) but also parks, gardens and turfed areas, which until then had been growing rapidly.

6. Table, figure and analysis from the report by Colsaet (2017).

Table 1.5. Overall change in major land uses over time in Île de France (figures in ha per annum)

Change in hectares per year	1982-1999	1999-2008	2008-2012
Agricultural areas	**– 1,806**	**– 1,870**	**– 796**
Ploughed land	– 1,777	– 3,416	– 252
Pastures	– 60	1,490	– 504
Other land	– 31	56	– 39
Natural areas	**– 409**	**660**	**153**
Forested land	– 165	– 138	83
Other natural land	– 338	724	44
Water	94	73	26
Artificial areas	**2,214**	**1,209**	**643**
Open space	549	274	– 148
Paved or built-up areas	1,700	1,193	707
Quarries, landfills and construction sites	– 35	– 257	84

Sources: IAU-IdF for MOS data, analysed by Colsaet (2017).

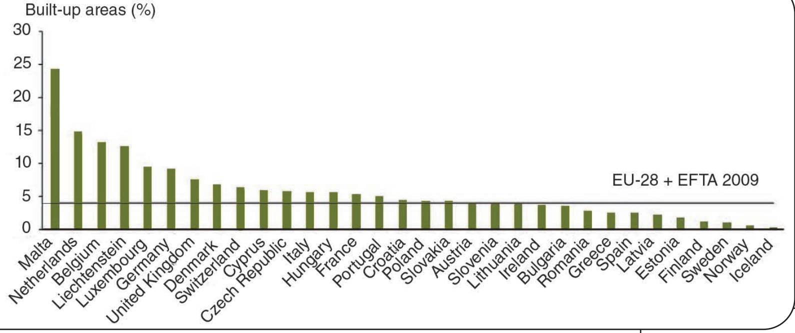
European and French trends

In Europe, according to CORINE Land Cover, land take increased by 2.7% between 2000 and 2006, which represents the equivalent of 107,800 ha of additional land lost each year to land take. France is, because of its vast surface area, the second largest contributor in absolute terms (13,200 ha/year) behind Spain (25,400 ha/year). In relative terms, however, the growth of artificialized surfaces is, at approximately 0.5%/year, close to the European average. This rate is similar to that of Italy, about five times slower than in Spain and twice as fast as Germany (where the population is decreasing). Although France is around the European average, we should still be concerned about this trend.

Focusing only on the built-up portion of impermeable soils (Fig. 1.6), the proportion of French land that is built-up is also close to the European average (5% in 2009). This is in contrast to the Netherlands (15%), Belgium (13%) or even Germany (9%) and England (7.5%), whose built-up footprint covers a much larger proportion of the land. Conversely, the Scandinavian countries, Ireland, and also Spain (2.5%) have proportionately less built-up area.

As highlighted in this report, Europe is undergoing dual trends; the concentration of activities and populations in urban areas, and urban sprawl with the extension of urban areas and peri-urban development. Within these trends, the dominant aspect of land take is sprawl. However, while this is reflected in a significant growth in built-up areas throughout the periphery, the highest rates of growth in built-up areas are observed at the immediate boundaries of the 40 urban agglomerations. Thus, in Europe, sprawl mostly occurs on the periphery of the zones already built rather than more distant areas.

Figure 1.6. Percentage of the total land area built-up by country in Europe, in 2009.



Source: EEA, 2016.

Conclusions and policy tools

Beyond the methodological debates and the important differences between the sources, it is clear that France, like the rest of Europe, is very concerned by the continuous increase of its artificialized soils. This trend, which has accelerated in recent times (except possibly in Île-de-France), is driven by an expansion of urbanised surfaces, as shown by CORINE Land Cover, and an expansion of impervious surfaces, rather than that of artificialized grassed or bare surfaces, as revealed by Teruti-Lucas. Nevertheless, neither of these two major sources makes it possible to be more precise in terms of the increase in land take in peri-urban and rural areas. Likewise, neither of these two sources makes it possible to evaluate the way in which the different types of artificial land combine to form a landscape mosaic combining impermeable surfaces and bare or grassy land. In fact, some of the issues involved in the impacts of land take are centred on these two dimensions; the development of land take beyond city borders, and the combination of waterproofed and non-waterproofed surfaces within areas of artificialized land.

Thus, while there is a need to move towards more convergent or more robust measures of land take, it is also necessary to better distinguish, on the one hand, its role and its progression within urban, peri-urban and rural areas, and on the other hand understand the different types of artificial land cover and how they relate to each-other. This requires, at both the local and national levels, maximising the potential of high-resolution remote sensing by integrating vector (cadastral and topographical) data and field data (statistics). The difficulty comes from the need for frequent updating and the high cost of such operations. It is therefore necessary to optimize processes to control costs, while at the same time setting an appropriate data acquisition frequency. The IGN creates a complete orthophotographic coverage of France every four years, a possible order of magnitude that could be adopted. The process proposed by the IGN for the creation of a large-scale land use layer (OSC GE) and applied to the former Midi-Pyrénées region provides an example of data-creation possibilities for the whole of mainland France, and highlights the need for coordination and decision-making at national level.

2. The impacts of land take on the characteristics and properties of soils

THE IMPACT OF LAND TAKE ON THE CHARACTERISTICS and properties of 'soils' in the pedological sense is inescapable, and in order to study it, it is necessary to distinguish between their physical, physicochemical and chemical aspects, on the one hand, and the biological aspects and biodiversity of their organisms, on the other (plant and animal biodiversity at the landscape level will be discussed in Chapter 3). A major difficulty encountered in the analysis of the scientific literature discussed here comes from the great diversity of situations and the frequent lack of precise characterization of the methods of land take or the types of soils on which the articles focus. This forced us to group the results into broad categories of land uses (the SUITMA categories are defined below) while trying to distinguish, where possible, the degree of disturbance and/or contamination and the amount and type of vegetation present (gardens, green spaces etc.) or predicted in the case of rehabilitated soils. Nevertheless, this categorisation remains largely insufficient to answer all the questions asked because it involves combining very different situations. The classification proposed in this chapter should therefore be considered as a rough draft that combines the use with the pedological characterization, and remains to be definitively established (Table 2.1), and we therefore identify this issue as a research priority.

Impacts of artificialization on the physical, physicochemical and chemical characteristics of soils

THE PHYSICAL AND CHEMICAL CHARACTERIZATION OF ARTIFICIAL SOILS is a very recent area of research. Awareness of the health and environmental risks associated with artificial soils first led to the study of mining and industrial sites in the 1990s, with the issue of soil contamination (metallic and organic pollution), with urban soils addressed more recently. At the same time, the developing focus on urban hydrology has led to a reconsideration of the role of soils in urban areas, which is essential in the management of water and material flows (suspended matter and pollutants) (see Chapter 3). The various functions of soils in an artificial environment have been identified as essential in maintaining regulation of the water cycle, pollutant degradation and retention, carbon storage, plant biomass production, and support for biodiversity within green areas.

Physicochemical characterization of artificial soils combines approaches from disciplines such as soil science, geotechnics and geochemistry. Artificialized soils have been mainly described and classified according to their uses. They have been grouped since 1998 at the international level under the acronym SUITMA (*Soils in Urban, Industrial, Traffic, Mining, and Military areas*). The physicochemical properties of these soils, with different degrees of land take, have been studied for a little over 20 years. This new body of knowledge is therefore relatively unconsolidated and not yet generalized

Characteristics and classification of artificialized soils

Characteristics of artificialized soils

Soils within artificialized areas are of two different types: soils in place, called 'natural', but which undergo the consequences of artificialization (e.g. heavy metals from atmospheric deposits or surface runoff), and soils that have been modified. For the latter, the predominant pedogenetic factor is human actions that overlay the other factors determining the natural soil formation (source rock, climate, etc.). Human activities transform layers of materials by mixing, compaction or aeration. they excavate and export soil material, leading to their partial or total removal, and they import earthy or technogenic exogenous materials (minerals, rubble, industrial or household waste etc.) which rapidly change the material and its subsequent evolution. Finally, they may seal the surface with coatings or constructions that are often almost completely impermeable.

The ancient and contemporary artificial soils present very contrasting characteristics according to the age of the site, its successive uses, the intensity of the input of technogenic materials and the processes of 'soil engineering' sometimes implemented to give the soil new functions or to restore lost functions. These artificial soils thus cover a wide range of pedological types, ranging from natural soils located in artificialized areas (some parks, allotment gardens, peri-urban agriculture etc.), to soils that are more or less truncated and/or enriched with technogenic materials, to soils constructed from earthy and/or technogenic materials during soil development or rehabilitation activities.

Typology of artificial soils within classifications

The classification of artificial soils relates to those for which the main pedological factor is humans, and does not concern those whose natural profile is preserved and which are described by already existing classifications. For these artificialized soils, the challenge is to have a reference system based on morphological descriptions and the definition of their specific characteristics, thus allowing comparisons and classifications.

Classical pedology is based on a morphogenetic approach to soil: it is based on the analysis of the soil profile, which is structured in horizons that reflect the pedogenetic processes that create its properties. Pedological classification systems mainly refer to forest (undisturbed) or agricultural soils, however some soil reference systems have recently incorporated artificialized soils into their typologies.

In the *French Soil Reference Manual* (RPF, 2008), artificial soils are termed *Anthroposols*. They are either soils of natural origin that have been transformed by anthropogenic processes to such an extent that they can no longer be linked to the original soil or to other natural types (transformed anthroposols), soils manufactured by humans (intentionally, via a 'pedological engineering' operation generally aimed at revegetation) by the addition of soil materials (reconstituted anthroposols) or non-soil waste (constructed anthroposols), or soils made entirely of non-soil materials (artificial anthroposols).

At the international level, the *World Reference Base for Soil Resources* (WRBSR) proposes equivalent terminology, which distinguishes between *Anthrosols*, roughly corresponding to transformed Anthroposols, and *Technosols*, which include artificial and reconstituted Anthroposols as a primary delineation.

However, these classifications are still based on soil morphology related to human interventions. It seemed essential to also include its use, in order to better quantify the potential, and the services to be expected from each soil (Morel *et al.*, 2014), hence the definition of SUITMA (Table 2.1).

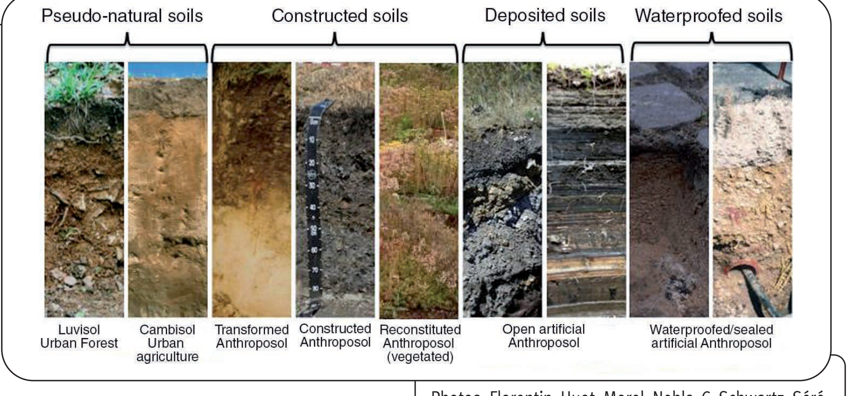
Table 2.1. SUITMA categories and soil types defined by the French Soil Reference System (RPF, 2008)

	Untransformed natural soils	Transformed Anthroposols	Reconstituted or constructed anthroposols	Anthroposols open artificial	Sealed/ waterproofed artificial anthroposols
Urban soil	Gardens, remnant agricultural enclaves	Gardens, urban agriculture	Landscaped gardens, greening of built-up areas	Urban wastelands	Built-on areas, roads, pavements, squares, car parks
Industrial zone	Natural enclaves		Vegetated surroundings of industrial installations	Vegetated surroundings of industrial installations	Industrial and logistics buildings and infrastructure
Transportation Infrastructure			Vegetated roadsides	Railway tracks, bare embankments, unpaved roads	Roads, airports, port facilities
Mining areas / quarries	Natural enclaves	Areas affected by the impacts of mining or quarrying activities	Rehabilitated land and quarries	Abandoned dumps and quarries	Sorting area, storage area, tracks
Military zone		Military exercise areas			Military infrastructure

While it seems obvious that the two main soil categories – natural versus Anthroposol – have very different properties, the information available in the literature does not always allow a particular soil to be linked to one of these two main categories. In addition, it would be desirable to distinguish between the different types of urban soil, in particular those of gardens (private or collective), parks or urban forests, building or roadside areas, and paved or built-on soils. Indeed, soil characteristics are highly dependent on practices: garden soils, for example, are generally very fertile, rich in organic matter and contaminated with certain specific pollutants (pesticides), whereas soils around buildings are much less fertile and generally compacted. Similarly, the impacts of pollution will be radically different: with risks of contamination of food in gardens but no risk of contamination of surface water or contamination of food for built-up or coated soils, etc. Nevertheless, this distinction is not possible given the available literature, in which the vast majority of soils are described as 'urban' or 'residential', without further provision of information.

To illustrate, Fig. 2.1 shows the variability of the horizons of artificial soils according to the category in which they belong.

Figure 2.1. The increase of urban influence on soils.



Photos: Florentin, Huot, Morel, Nehls, C. Schwartz, Séré.

Characteristics and properties of artificial soils

Although these soils undergo significant modification by humans, and are often dominated by the presence of artificial materials, artificial soils are currently characterised using the same physical and physicochemical criteria as for natural soils.

The analysis and interpretation of changes in the characteristics of these soils must be associated with a reference condition, which is very difficult to define. In the publications reviewed here, the reference soils are either agricultural (in 20-30% of the cases) or forested and close to the study area. However, the reference land use is not specified in more than half of the cases, and often there is not even any reference soil. Comparisons with adjacent agricultural soil may be justified insofar as the majority of the artificial soils were originally used for agricultural production. However, without clear benchmarks, it remains difficult to draw conclusions on the quality of man-made soils and its positive or negative evaluation over time.

Characteristics influencing water transfer and plant development

Soil infiltration capacity is one of the main properties affected by artificialization. It is associated with the very important issue of runoff, and therefore the risks of both flooding and water erosion. It is estimated that 60 to 70% of artificial soils are impermeable, and those that are not are likely to be compacted by development activities.

More broadly, beyond these surface properties, the structure of artificial soils is very often disturbed, and marked by a high level of stoniness due to the contribution of allochthonous/exogenous materials (demolition materials, landfill waste, and mine residues). Depending on how they are deposited, these materials can constitute impenetrable barriers to root development. In addition, they often have low water retention capacity and low nutrient reserves that limit plant growth.

The compaction of artificial soils is a consequence of the use of these soils (construction of infrastructure, buildings) and, for exposed soils, depends on the type of vegetation cover. Trampling, and the recent creation of a residential area, are factors in increasing the density of materials, which results in a strong decrease in infiltration capacity.

Land take usually leads to a modification or removal of the surface horizons and the destruction of the vegetation cover, which weakens the soil structure and exposes it to the direct action of rain and runoff. The result is an increase, at least temporarily, in the risk of water erosion before a new stability is established. Vegetated areas thus present a period of high vulnerability after development, before soils stabilize and vegetation establishes and protects them. It has been shown in Mediterranean environments that erosion can seriously compromise the revegetation dynamics of soils undergoing rehabilitation. The construction of impermeable anthroposols leads to a local increase in runoff, which can lead to accelerated erosion of the surrounding soils. On mining soils, water erosion can cause serious pollution (heavy metals, acid mine drainage, etc.).

Soils with a high degree of spatial heterogeneity

In a natural context, soil is naturally heterogeneous both horizontally and vertically. The artificialization of the same soil for various uses and in various forms over time adds to this heterogeneity. The determination of the characteristics of artificial soils is thus complicated by this spatial heterogeneity. Characteristics can significantly vary within a few metres under the same land use, and the alteration processes are severe and rapid. In addition, comparisons are made difficult by the diversity of sampling methods and analytical techniques used to measure physical properties and chemical composition.

The physico-chemical variables most often measured in artificial soils are bulk density, hydraulic conductivity, organic matter content, cation exchange capacity (CEC) and electrical conductivity (EC), which are generally little different on the surface from those of reference soils, as well as pH, which is often higher than 7 due in particular to the presence of carbonated technogenic materials (concrete, cement, etc.), which are common in urban soils and in infrastructure. There are also acidic artificial soils, particularly metalliferous mining and industrial soils, which can even be highly acidic pH (< 4) in more than 40% of cases.

Heterogeneous organic carbon dynamics

Organic carbon (C) stock has a direct effect on soil functions such as water holding capacity, nutrient storage, nitrogen and carbon cycling, and plant development, and an indirect effect on water flow and climate regulation functions.

Several French studies have shown that exposed artificial soils have higher average carbon concentrations than other soils, but with great variability. In urban areas, collective vegetable garden soils are characterized by high levels of organic carbon and nutrients (see Box 2-3). Other urban soils show a strong decrease in C stocks, due to the change of use and the suppression of vegetation cover. For example, soil sealing can reduce the stock of C because it results in a stripping of the surface layer, which is generally more organic, and by not introducing fresh organic matter. Conversely, it can protect the deep organic layers that were formed during previous uses that led to the formation of the soil.

Potential soil C stocks depend on the type of vegetation cover and its age. They will be higher in an urban mixed forest than in a forest composed solely of hardwoods or softwoods. Surface soil horizons under urban grasslands (10-30 cm deep) can sequester up to twice as much carbon as forest soils; this is thought to be related to the higher root biomass of grasses in the first 30 cm of soil, and to the intensive management of grassy areas (mowing, watering, fertilizing) that increases root production. The C cycle in urban soils is also affected by compaction, which limits the root development of trees and thus their C storage. Macrofauna (especially earthworms) accelerates the decomposition of organic matter and its mixing, and increases the C content of the top soil horizon.

Significant pollution by trace metal and metalloid trace elements (MTE)

MTEs or metallic and metalloid trace elements are the pollutants that have been most measured and studied in industrial, urban and mining soils. The metals that are monitored are generally zinc, copper, cadmium, lead, nickel and chromium. Some studies focus on several metals, while others focus only on a few, depending on the context of the study. The concentration levels measured in urban areas show an increase in MTE concentration, mainly in the soil surface layer (up to 20 cm deep), in comparison to 'control' areas (agricultural areas, parks away from the city, forest soils, or geochemical background values published in the literature). Indices to classify soils by pollution level have been developed (enrichment factor per element, overall pollutant load index). The approaches vary:

they take reference to values from the literature, national or locally measured values, or regulatory thresholds existing in the country or defined at the European or international level. Overall, there is a link between urban density, the age of soil artificialization and the concentration of metals in the soil. However, two different situations can be distinguished:

- *a diffuse pollution context,* where soils have undergone little reworking and contain few technogenic materials undergo a surface enrichment in metals, due essentially to atmospheric inputs from industrial and urban activities. These, in particular, include excess concentrations of MTEs linked to the fallout of atmospheric microparticles and nanoparticles (air transport of dust, automobile traffic, heating), the leaching of materials (roofing, or even wall materials) and roads (wear and tear on car parts, snow removal salts etc.). In this case, we refer to an overall urban signature. Although the raised concentrations generally do not exceed thresholds associated with known or potential toxic risks that would require the prohibition of certain land uses, this should not exclude case-by-case checks;
- *a concentrated pollution context,* in highly modified soils containing materials (sediments, waste, industrial product residues) rich in certain MTEs, or in the vicinity of industrial sites emitting polluting atmospheric emissions. The identification of metal sources is then much more precise, but the contaminations are very specific to the materials mixed in the soils. However, the interpretation of metal content in mining and industrial soils is often complex, due to changes in activities that have generated various types of waste and excavated material, and the lack of information on the conditions under which soils are established. ETM concentrations can be 10 to 50 times higher than average measures from urban areas, and these soils, whether on the surface or historically buried deep underground, present real risks of contamination of the subsoil and toxic risks for humans and their environment.

It should be noted that urban soil pollution is largely historical: sources of pollution, which have now disappeared, have contaminated the soil (e.g. lead from petrol, cessation of polluting industrial activities, etc.).

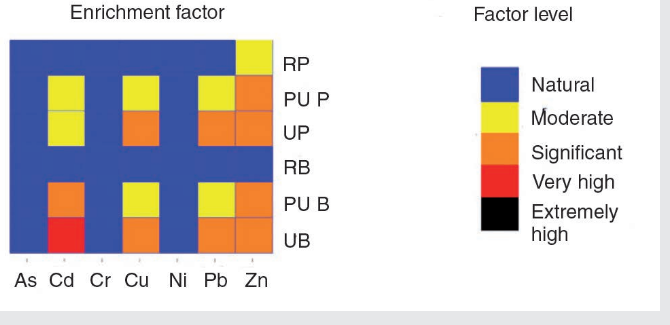
A 'gradient' between the more contaminated central urban area and the peri-urban areas has been demonstrated in recent years, although a finer relationship between land cover and ETM concentration in soils along a gradient is not evident: the variability of the measurement and the small number of samples generally make it impossible to establish statistically valid trends.

Urban soils are therefore storage interfaces for trace metals. Observations show that the solubility of metals and their potential mobility are generally low. With characteristics conducive to the retention of metal cations (carbonated soils, enriched in organic matter, vegetated), urban soils act as sinks for these MTEs, which may have been accumulating on the surface or in certain horizons for several centuries. A study carried out in Île-de-France confirms and quantifies this storage of MTEs, particularly cadmium (Box 2.2), while particular attention is paid to urban garden soils because of the public health issues they represent (Box 2.3). In the case of metalloids, which have received very little attention in the literature with regard to artificial soils, the alkaline pH of urbanised environments would be more favourable to their mobility. The potential mobility of these contaminants is therefore essential to consider when considering the long-term management of these surfaces and the reversibility of uses in urban areas.

Box 2.2. MTE concentrations along an urban pressure gradient in the Paris region

A very recent study (2017) measured the MTE contamination of 180 lawn or wood soils distributed in Ile-de-France. Copper (Cu), cadmium (Cd), lead (Pb) and zinc (Zn) are of anthropogenic origin, while arsenic (As), chromium (Cr) and nickel (Ni) are of natural origin. Road traffic has been identified as the primary anthropogenic source of MTE, and industrial activity, notably cement works, as the second source for Cd. Characteristics such as texture, organic carbon and total nitrogen levels reflect the origins and legacies of soils, which can often explain their MTE levels. Urban wooded soils appear more contaminated than lawn soils, probably because the wooded areas are much older (they date from the late 19th Century). The capacity of forest cover to increase the flow of certain MTEs due to their foliage cannot be excluded. Urban lawn soils are similar to fertile agricultural soils; imported from the Paris surroundings especially from the 1950s onwards, they have been exposed to urban conditions for a shorter period of time for the influx of MTEs.

Figure 2.2. MTE increases in soils in Ile-de-France.



EF: enrichment factor, relative to the local geochemical baseline (presumed free of anthropogenic contamination). R: rural, PU: peri-urban, U: urban, P: lawn, B: wooded.
Source: Foti *et al.*, 2017.

Concentrations of anthropogenic MTEs increase from rural to urban areas (Fig. 2.2), where they often reach or exceed regulatory thresholds. Heavy cadmium pollution of urban wooded soils poses a significant risk to biological communities.

Box 2.3. The special case of urban garden soils

While many studies have highlighted the potential contamination of urban vegetable garden soils by MTEs, their fertility, resulting from highly intensive and varied cultivation practices, should also be highlighted. Compared to agricultural soils, garden soils have higher levels of organic matter (>4% on average, compared to 1-3%) and, in 70% of cases, very high nutrient levels. However, they also have total metal contents that are, on average, twice as high; they are linked to the repeated use of fertilizers and pesticides (a major source of pollution), solid waste inherited from former mining or industrial activities, and industrial, urban or traffic emissions. In the long term, metals or organic pollutants can accumulate in these soils, reaching concentrations that are toxic to humans and ecosystems.

The overall quality of garden soils is highly variable. A recent study of four European cities showed that, at the city and garden scale, the variability observed for the main soil properties is dominated by the local geology (the parent material), and by gardening practices, which differ from one country to another. The range of concentrations of MTEs is similar for three of the four cities. Extreme values are observed for copper, lead and zinc, which are mainly explained by the historical and environmental circumstances of the sites (reflecting the influence of the history and succession of land uses), and inputs linked to external factors (industrial activities, road traffic, etc.).

Contamination by organic pollutants remains poorly understood

For more than 20 years, studies have looked at urbanised or industrial soils, with measurements mainly concerned with the concentration of all hydrocarbons and polycyclic aromatic hydrocarbons (PAHs), as well as their fate. There is an abundant literature on the characteristics of PAHs in brownfield soils, but far fewer on urban soils. These measurements are often coupled with those of MTAs at the same sites in an overall assessment of the physicochemical quality of the soil. The specific research on hydrocarbons is linked to their industrial origin (the legacy of the steel industry in many industrial sites in France and Europe) or to automobile traffic. With regard to PAHs, it is noteworthy that the main results are similar to those for heavy metals. Artificial soils form storage areas for PAHs that have persisted for almost 100 years on certain industrial sites, they are not very mobile because of their low solubility and, similarly, depending on the type of input (atmospheric or direct input by PAH-rich waste), the soils are highly contaminated or enriched only on the surface or in the horizons containing the waste.

Very recently, research has been undertaken on certain emerging organic pollutants. However, analytical difficulties remain for some (e.g. flame retardants such as polybrominated diphenyl ethers or PBDEs, organochlorinated pesticides, drug residues, etc.) due to the presence of these molecules in ultra-trace amounts, and sampling strategies poorly adapted to these molecules in these very heterogeneous environments. The study of these pollutants in soils is complex because it is necessary to measure not only the concentrations of several congeners, but also the metabolites produced during the degradation of these molecules in soils, which are sometimes more mobile and more toxic. Persistence times and volatility are also important considerations. With regard to reference levels, we found only one publication that measures PBDE concentrations in forest or grassland soils, in the United Kingdom and Norway, with mean concentrations of 600 to 2500 ng/kg. The few other references dedicated to emerging pollutants in urban soils instead focus on evaluating the mobility/volatility of these molecules and their half-life under controlled conditions, and show the potential mobility of these molecules and their metabolites in the subsoil.

Towards synthetic soil quality indicators for better management

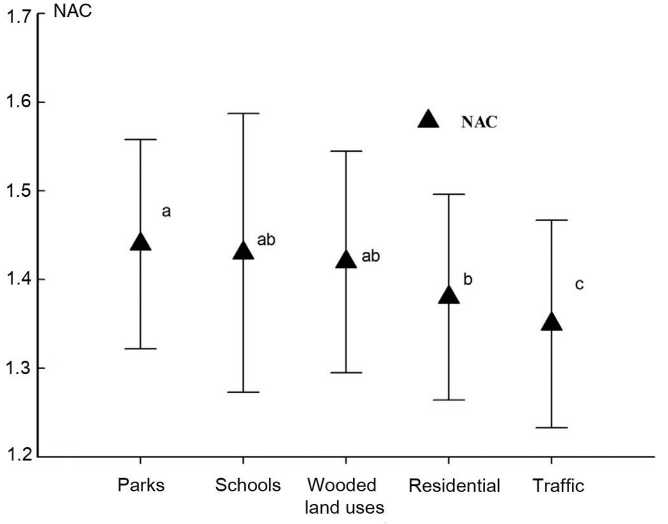
Soil quality indicators have long been used for agricultural soils to assess their fertility. Artificial soils have been comparatively rarely assessed according to such frameworks. The use of indices in the case of artificial soils has two objectives: on the one hand, to effectively assess their fertility, in particular in relation to agricultural soils (since artificial soils are mostly former agricultural soils), and on the other hand to attempt to establish a link between the intensity of artificialization and soil quality via correlations. One of the expected outcomes is that these quality indices will be taken into account in development projects or, even more effectively, in urban planning, so that the soils with the best potential in terms of ecosystem services can be preserved during planning. The production of indicators can also have the more general aim of warning about the degradation of soil quality associated with increasing urbanisation.

In the literature, the characteristics of soils are presented according to their use, in order to highlight a potential positive relationship between the increase in the degree of artificialization and the increase in pollutant concentrations and/or the change in soil fertility parameters. The quality indices can be of different levels: a parameter, or an aggregation of parameters with all associated details of the weighting of the parameters used. Studies presenting indicators as well as their application to land use optimization are rare. However, indices with an integrative aim have developed considerably, although they do not integrate many of the soil characteristics, but rather are mainly used to describe losses in soil functionality

For example, the NAC (Natural pollutant attenuation capacity of urban soils) index combines the percentage of organic carbon, percent clay, bulk density, pH and total nitrogen. If the index classes are defined appropriately, it is possible to show trends between the NAC value and the type of land use (Fig. 2.3). NAC is also correlated with the age of artificialization (concept of soil *resilience-recovery*).

In France, discussions concerning the possibilities of integrating the concept of soil quality into land use planning projects are ongoing. One example is the UQUALISOL-ZU project (GESSOL programme), which considers soil and its physicochemical, microbiological and physical characteristics, on the one hand, and land use and occupation on the other. A ‘land use’ oriented index, based on the functions performed by the soil for each of the

Figure 2.3. Natural attenuation capacity of urban land pollutants according to land use in the city of Beijing.



Source: Wang *et al.*, 2015. Dimensionless index; higher values indicate higher capacity. Values shown: mean ± standard deviation.

uses identified in the geographical area, was thus designed (Keller *et al.* 2012). The advantage of this multi-purpose use index is that it is relatively easy for decision-makers to understand (Fig. 2.4). There is growing interest in this qualification of soils via synthetic indices. But there is not yet a consensus on the most relevant and essential parameters for describing the characteristics and potential of these soils. However, contamination regulations (calculations of exposure and health risk for the population) seem to play a leading role in the characterisation of these soils.

Summary of the physicochemical characteristics of artificial soils

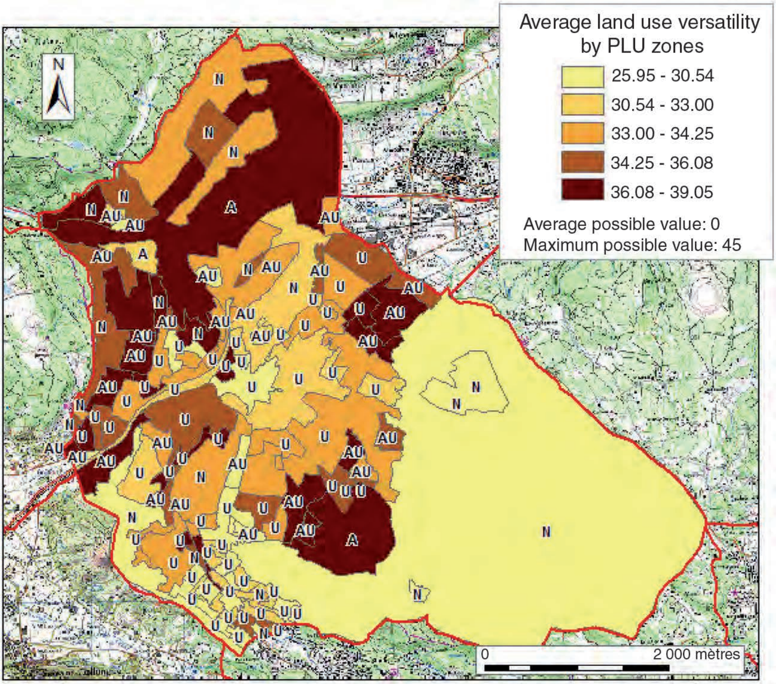
In summary, SUITMA is characterized by:

• extreme spatial variability linked to the complexity of their history, from a scale of millimetres to metres, for urban soils formed from modified and displaced materials, but also affected by atmospheric inputs;

• a high degree of rockiness, particularly at depth for mining soils, linked to the installation of transport infrastructure, which frequently leads to high compaction rates;

• the nature of the technogenic materials they contain, their abundance, and their size;

Figure 2.4. Map of land use versatility by Gardanne PLU zones.



The letters shown on the surfaces correspond to the PLU zoning: U: urban, A: agricultural, N: natural, AU: to be urbanised.

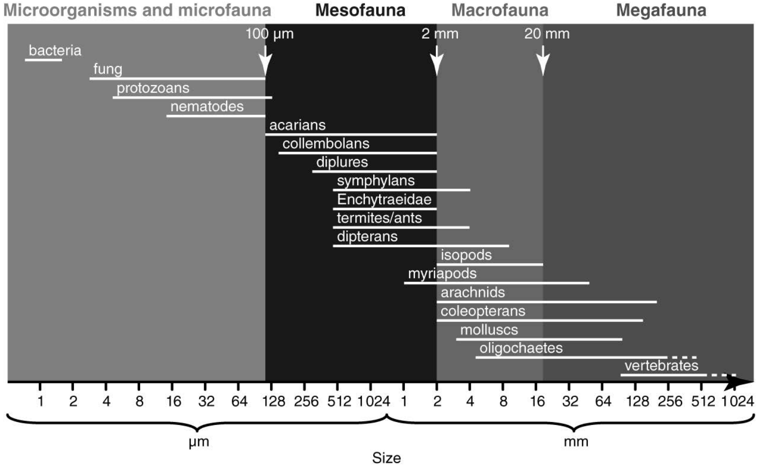
- a strong decrease in infiltration and water retention capacity related to waterproofing and compaction, excluding vegetated soils (green spaces, parks and gardens and urban agriculture areas) and devices dedicated to rainwater infiltration;
- pH levels frequently above 7 for urban soils and those of transport infrastructure, or on the contrary acidic to very acidic for mining and industrial soils;
- highly variable organic matter contents depending on land use (high in open soils such as vegetable gardens and lawns, and low in sealed urban and mining areas) and its origin, but with surface layer contents on average higher than in non-artificial soils;
- high concentrations of heavy metals (Pb, Zn, Cu, Cd, Ni), mainly in the surface layer, as well as polycyclic aromatic hydrocarbons in urban and industrial soils. These pollutants, stored and not very mobile in soils, represent secondary sources of diffuse pollution in the subsoil, surface water by erosion/runoff, groundwater and the atmosphere;

• a lack of knowledge on the concentrations of certain emerging pollutants (platinoids, flame retardants, certain pesticides or drug residues or polar aromatic compounds resulting from the oxidation of PAHs).

Impacts of land take on soil organisms and biodiversity

Because of their structure, the diversity of their physicochemical characteristics and the microclimatic conditions, soils are home to a huge number and very great diversity of organisms (about a quarter of the animal species described). Microorganisms represent the main soil organisms in terms of biomass and diversity. They are essential for the functioning of terrestrial ecosystems and in particular of soils (biogeochemical cycles, fertility, regulation of gas and water flows, etc.). To simplify the representation of the diversity of these organisms, species are grouped according to their size in Fig. 2.5.

Figure 2.5. Illustration of the diversity of soil fauna, from the smallest organisms (bacteria, protozoa) to the largest (earthworms, amphibians, vertebrates).

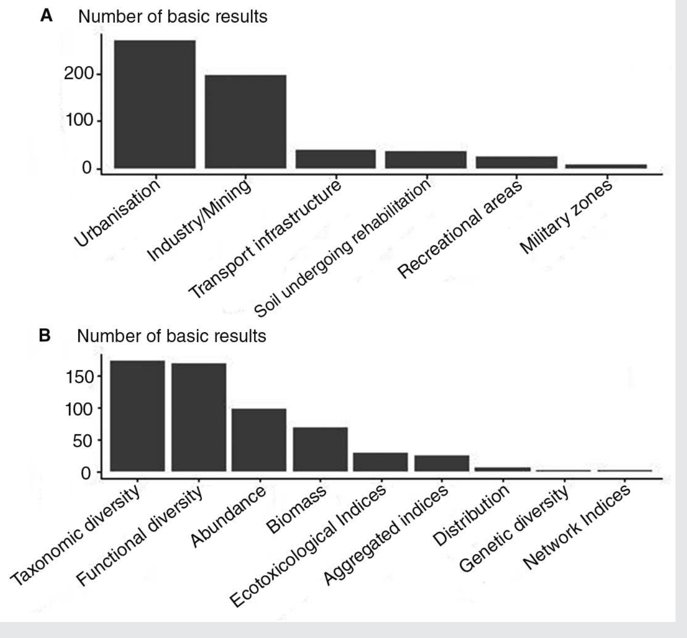


The analysis is essentially based on artificial soil studies carried out in 'real' situations (urbanised areas, around industrial or mining installations), and not under experimental conditions. By far the most studied categories of land take are urbanisation (often without further details on the nature of disturbances to the soil) and mining or industrial activities (Box 2-4). Diversity measures (functional composition and taxonomic structure) are most often used to estimate the effect of land take (29% and 23%, respectively), followed by

Box 2.4. Analysis of the literature

The selected literature includes 209 scientific articles, mostly published in the 2000s. The studies come mainly from Europe (65%). The data set is very balanced between the three groups of organisms (36% macrofauna, 32% meso-microfauna, and 31% microorganisms). The most studied categories of land take are urbanisation and mining or industrial activities (Fig. 2.6.A). Most studies are conducted at the level of communities of organisms. These soil microbial and animal communities can be characterized by various ecological indices: their abundance and biomass; their taxonomic or functional composition; and their taxonomic or functional structure (Fig. 2.6.B).

Figure 2.6. Land uses studied (A) and response variables measured (B) in the analysed literature.



This literature was systematically analysed. Since the same scientific paper may contain several results (on groups of organisms or response indicators of different organisms), each publication has been broken down into basic results. Thus, the analysis was broken down into 582 basic pieces of information. For each, the result obtained by the study was characterized as belonging to an effect class and, when possible, by a score (from -1 for a very negative effect to +1 for a very positive effect, and 0 for no effect). This individual score makes it possible to calculate, for a given type of effect (an artificialization factor for a group of organisms and for a response indicator), an average score from all of the relevant publications (Fig. 2.6).

abundance and biomass measures (17% and 12%, respectively). Other measures, such as network indices or bioaccumulation, are more anecdotal and account for less than 20% of cases (see Fig. 2-6).

Effects on different groups of organisms

Land take drivers are described very inconsistently across the articles. In the case of industrial mining activities and road infrastructure, it is possible to know relatively precisely what the environmental pressure gradient (metal pollution, PAHs, etc.) or habitat destruction/fragmentation corresponds to. However, in almost all studies dealing with urbanization, it is impossible to break down the contributions of the various land take factors (fragmentation/disappearance of habitat, pollution, waterproofing, etc.). Moreover, most studies compare soils in urbanised contexts with different types of use or compare urban soils with 'similar' soils in rural contexts, but they are often different from a pedological point of view and therefore difficult to compare, and there is no consensus on reference soils (see § limits). We describe the results by groups of organisms below before presenting the overall results on soil biodiversity.

Effects on microorganisms

A synthesis of the effects of the different land take factors on diversity measures or on taxonomic groups of microorganisms shows that, generally, the effects are negative to very negative. However, there is a significant difficulty in selecting reference soils for estimating effects. Some studies show a fertilization effect (via nitrogenous atmospheric fallout or the addition of compost or fertilizers to urban green spaces) that can explain some of the positive impacts of urbanization on microbial communities.

Studies on the impact of industrial or mining activities and road traffic mainly concern contamination by heavy metals (local or more diffuse, around sites) or by PAHs (cyclic aromatic hydrocarbons), and overwhelmingly report negative effects, in particular on biomass and/or microbial abundance, and on microbial activity variables.

In the urban context, studies highlight the negative effects of urbanization on biomass or microbial abundance as well as on soil microbial activity, but it is difficult to distinguish the effects of the various land take factors. Urbanization includes physical disturbance (removal or mixing of soil horizons, sealing, and compaction), chemical disturbance (atmospheric deposition, fertilization) or ecological disturbance (removal or replacement of vegetation) of soils, and it results in high soil heterogeneity with different properties and practices, and thus variable effects on microorganisms. All of the results presented above concern artificial but 'unsealed' soils: waterproofing always leads to negative effects with a strong reduction in biomass and soil microorganism activity.

In general, there is a weakness in the available literature on the evaluation of the impact of soil artificialization on microorganisms, given the importance of the latter in many ecosystem processes and services (soil fertility, water purification, carbon sequestration etc.)

The evaluation of the impact of soil artificialization on microbial diversity in the strict sense and on the networks of interactions in soils remains very limited, although new mass-sequencing methods could now make it possible to address these issues and, combined with functional approaches, to assess the consequences of changes in microbial diversity on ecosystem processes in soils.

Effects on meso- and micro-invertebrates

The effects of the urban environment on micro and mesofauna vary according to the sampling sites and the measured parameters, and according to the management of urban sites. Several studies show that biodiversity is more favoured in urban areas than in other highly anthropized ecosystems, particularly agricultural ecosystems. A recent study of approximately 760 samples representing all types of land use in France (including 30 from urban vegetable gardens) showed that soils sampled in urban settings contained far higher diversities of springtails and mites than did most agricultural soils. This is particularly the case for allotment garden soils that are rich in organic matter and have a diversity of micro-habitats that are very favourable to the development of diverse communities. This is also the case for certain specific ecosystems, which are created in vegetated roofs, stormwater management structures (retention/infiltration basins) or landfill sites. It would appear possible to improve anthroposols so that they are more favourable to the development of biodiversity, in particular by increasing the input of organic matter (Biotechnosol - GESSOL 3 project).

In contrast, mining or industrial activities negatively affect micro and mesofauna communities, with effects generally much more marked than in urban contexts, due to pollution or soil modifications that are often much more severe.

Effects on macrofauna

Overall, soil macrofauna is also negatively impacted by soil artificialization. Whether it be spiders, carabid beetles, ants, wood lice or other macro-invertebrates, the consistency of the conclusions allow us to establish a response pattern of macroinvertebrate diversity to the urbanization gradient. Positive outcomes emerge when looking at urban soil ageing or soil rehabilitation/restoration practices. With regard to response variables, the functional composition of communities is negatively impacted by all artificialization factors, making it a binary (yes/no) indicator. The indices of taxonomic diversity, functional composition and abundance measures present a range of responses to the artificialization factors, and are therefore relevant for assessing the intensity of these different artificialization factors. It is therefore imperative to study the response to artificialization with a combination of biological/ecological indicators.

Urban macrofaunal soil communities are dominated by a small number of species and tend to have a lower proportion of detritus feeders (soils with lower organic matter content) and forest-specialist species (even in urban remnant forest habitats). In addition, they harbour higher proportions of small, energy constrained, highly dispersive individuals that prefer open, less humid and warmer habitats. Generalist species with a wide biogeographic distribution are over-represented in urban areas. Similarly, exotic, invasive, or opportunistic species may find environments closer to their original biogeographic zone in urban areas, notably due to the urban microclimate.

The abundance of terrestrial arthropods near contamination sites related to industrialization, infrastructure or mines is generally reduced. This reduction can be explained by the significant negative effects on soil arthropods, particularly on decomposers and predators.

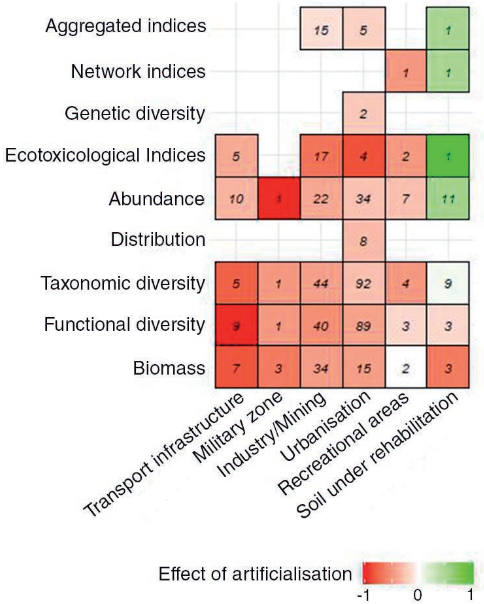
Summary of the effects of artificialization on soil biodiversity

The effects observed in the analysed articles appear to be consistently negative to very negative for all forms of land take (Fig. 2.7), except for rehabilitated soils, for which most indicators are neutral or positive, and to a lesser extent for ‘recreational areas’, which themselves cover a wide variety of situations, from sports fields to urban parks or vegetable gardens. This result indicates a potential for reversibility of the impact of artificialization on soil organisms, at least where such rehabilitation is possible. Among the most documented uses, soils from infrastructure and industrial and mining activities are generally the most heavily impacted with regard to soil organisms, both in terms of taxonomic diversity and assemblage composition. The few studies on sealed soils (road surfaces, pavement/surfacing in residential areas) always show very negative effects of sealing on soil microbial communities, in relation to the absence of vegetation and the lack of exchanges (water, nutrients) with the surface. We did not find any studies concerning soil fauna, even though the latter is probably also heavily affected by sealing.

Artificialization linked to industry and mining operations has very localized (installations) and/or diffuse effects (areas around installations affected by atmospheric deposits, waste etc.). The impact of these activities is generally linked to soil contamination by clearly identified compounds (heavy metals, nitrogenous or sulphurous deposits, trace elements). Available studies show some variability in the impact of these contaminations on soil micro-organisms, while a consensus on negative to very negative effects appears for soil fauna. This variability for microorganisms is explained by differences in the bioavailability of contaminants, which are related to soil characteristics (pH, texture, CEC, etc.), and by differences in the sensitivity of the microorganisms and microbial functions under consideration. An important point concerns the resilience of communities: negative effects are observed long after the closure of facilities, with community structures still marked by disruption or ongoing stress. The ‘restoration’ of ecosystems generally involves revegetation, but it is often at best rehabilitation, as the desired functions can be restored without the final ecosystem being equivalent to its initial state.

Artificialization linked to urbanization involves various factors which are often in combination: physical alteration of the upper layers of the soil, contamination by compounds linked, for example, to automobile traffic (heavy metals, hydrocarbons, etc.), waterproofing, compaction, management practices (for example, in urban green spaces), fertilization,

Figure 2.7. Effect of land use on response variables of all soil organisms.



The X and Y values are given in Fig. 2.5. The numbers in the boxes correspond to the number of cases.

pesticide treatment, watering, export of litter and grass clippings, etc.). In this context, it is difficult to characterise the relative effect of these different artificialization factors.

In urbanization studies that do not target contaminants, the role of soil organic matter appears to be quite central. Studies frequently compare 'urban' soils with 'rural analogues', but these soils are often different from a pedological perspective and therefore difficult to compare.

The information collected in this ESCo supports several ecological hypotheses. The 'urban ecosystems convergence' hypothesis suggests that anthropogenic factors (management, practices) are more determinants than are environmental factors (parent material/soil geological substrate, climate, etc.). In many studies, the increase in environmental pressure leads to a decrease in biodiversity values, which concurs with the hypothesis of 'increasing disturbance' as a function of the artificialization gradient which, itself, can be combined with a decrease in resource availability or other pressures (cocktail effect). However, a measured biodiversity variable (e.g. number of species) may also remain unchanged along the land take gradient, but with a decrease in habitat specialist populations as environmental pressure increases, to the benefit of generalist species.

Strategies to limit the impacts of artificialization on soil properties

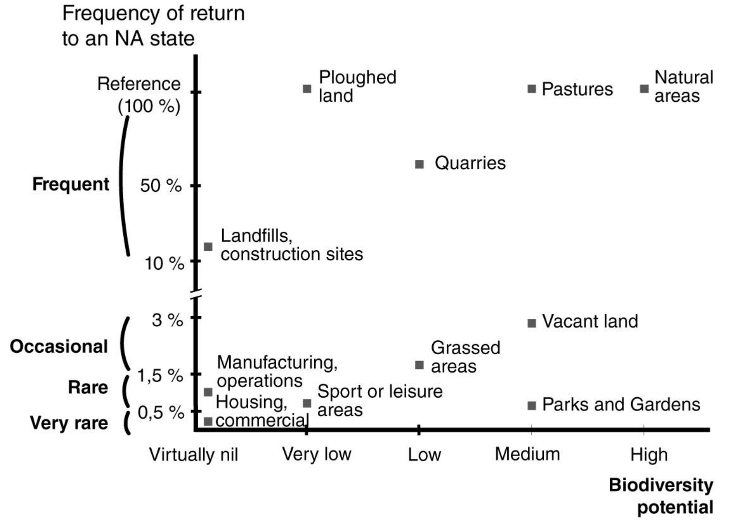
The impact of land take on the physical, chemical and biological properties of soils that enable them to continue to perform their functions as well as possible, will be reduced and made more reversible if these properties have been taken into account and preserved as much as possible at the time of development projects and other works on sites. A distinction must be made here between the three main categories of artificial soil.

For built-on soils (17% of artificial soils in 2014 according to Teruti-Lucas), the potential for intervention is reduced: limiting impacts requires various solutions for greening façades and roofs, and especially on the management of soils surrounding buildings by promoting infiltration and greening (see Chapter 3). It is clear that reversibility will in all cases be very difficult, costly to implement and therefore very rare (Fig. 2.8). It implies the destruction of buildings, the removal of technogenic materials, and then the application of soil engineering techniques (see below). Examples of land recycling and an analysis of this concept are presented in a recent EEA report (2016).

For other sealed, covered or stabilised soils (47% of artificial soils), the scientific and technical literature shows that different techniques can be considered and tested to reduce surface sealing and erosion risk, or improve the biological properties of soils. Semipermeable coatings can replace impermeable surfaces to promote water infiltration. They are made of slabs or pavers separated by joints filled with a permeable material (such as sand with a high organic matter content). This system acts as a rainwater filter and favours flows between the surface and the soil; however, it tends to become clogged as it ages. Such an option particularly concerns parking areas and areas peripheral to transport infrastructure or logistics warehouses, and therefore represents significant potential. Drainage ditch networks are particularly important because they can improve both reinfiltration and sediment trapping. However, in the absence of maintenance, their effectiveness may decrease over time due to accumulation of deposits. They also form vegetated corridors favourable to biodiversity. The reversibility of these surfaces is potentially more important than for built soils but can, in certain cases, be constrained by contamination problems, in which case it would be necessary to use decontamination techniques (see below) that are often cumbersome and costly. Effective reversibility is probably very rare, particularly in the case of linear forms (roads, transport infrastructure) because of their utility value, whereas non-linear forms (urban or industrial wastelands) or soils merely stabilised (lateral footprints of impermeable linear structures) can be the subject of remediation, reconstitution or even soil construction techniques (see below).

Artificial soil that is not sealed, bare or grassed/vegetated, which, according to Teruti-Lucas, represents more than a third of artificial soil in 2014, constitutes a very heterogeneous group (ornamental gardens or vegetable gardens, sports and leisure grounds, but also building sites, quarries, mining sites, etc. It nevertheless offers the greatest potential for limiting environmental impacts and for reversibility. Fig. 2.8 illustrates the significant effective reversibility of quarries or landfills, in particular, bearing in mind that in the

Figure 2.8. Biodiversity potential and frequency of return to a non-artificial state observed in Île-de-France over the period 1999-2012.



Uses are based on MOS IdF and the biodiversity potential corresponds to the BioMos indicator (average suitability for biodiversity, according to experts). After Colsaet, 2017.

classification adopted, 'reversibility' does not mean that the soil has necessarily regained characteristics equivalent to a 'natural' soil.

A primary impact of this type of artificialization is the risk of water erosion at the time of construction and for soils that remain bare. Numerous technical studies have shown that, compared to bare soils, anti-erosion approaches in urban areas, such as green cover or wood chip mulch, can reduce erosion by up to 80%. However, field observations show that these methods are not as effective as expected due to the use of inappropriate techniques and, in particular, their implementation at too late a stage (60-80% of erosion occurs during the initial construction phase).

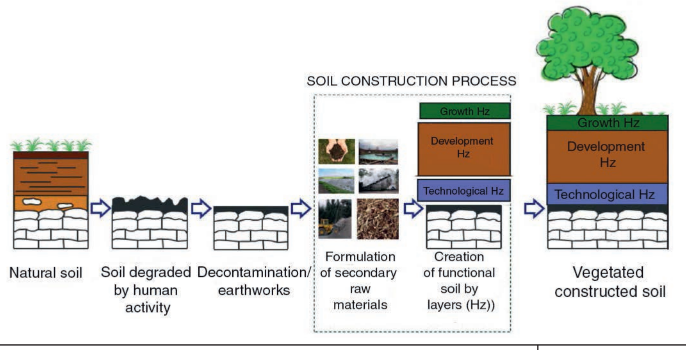
For these unsealed soils, an initial application of organic matter in large quantities, or several successive inputs when the artificial space permits, appears to be effective in maintaining or building carbon stocks in artificial soils and directly improving certain functions such as water retention, nutrient storage, plant development and, indirectly, the regulation of water flows and local climate through mitigation of greenhouse gas emissions. It has, for example, been shown that adding compost to a depth of 60 cm allows, after four years, the formation of stable aggregates, between 15 and 30 cm, in which the organic matter is protected.

Mine soils are relatively unstable and inconsistent in texture, with coarse element loading and reduced nutrient and organic matter content. All studies conclude that remediation of mining areas is necessary to limit erosion and pollution risks, and to allow rapid establishment of vegetation. Remediation trials on these soils all involve the application of soil improvers (to correct pH, increase organic matter content and improve cation exchange capacity) and fertilizers. These inputs make it possible to reduce the phytodisponibility of metallic and metalloid trace elements and to increase biological activity and fertility, thus favouring the establishment of spontaneous or planted vegetation, which leads to a certain reversibility in the degradation of these soils.

Brownfield sites are characterised by a wide diversity of contamination sources, resulting in soil pollution that is predominantly mineral or organic, and there is often multi-contamination. The choice of soil decontamination process(es) (physical, chemical or biological) and the location of implementation (in situ, on-site, off-site treatments and/or containment) is then guided by the nature of the pollutants present and by their risk of release into the ecosystem and to humans, while taking into account site development objectives. Recent developments in the management of degraded sites and soils aim to consider them as resources by integrating, specifically, the ultimate stages of ecological re-functionalization of the soil and, more broadly, the ecosystem initially polluted. Ecological engineering processes (e.g. soil engineering, plant engineering) are then developed so that the treated brownfield sites can again provide ecosystem services.

Soil construction is a soil engineering process (Fig. 2.9) that seeks to establish a soil structured in layers or functional horizons (constructed anthroposol). This process is based on the existing production of organic and/or mineral by-products and waste, and uses abandoned or low value materials. It involves combining materials together in order to

Figure 2.9. Diagram illustrating the different stages in the implementation of soil engineering for soil construction and ecological re-functioning of degraded sites.



After Séré *et al.*, 2008.

build functional soils with the required properties, thus enabling the production of various ecosystem services (biomass production, support for biodiversity, water filtering and storage, carbon storage, climate regulation). Soil construction is distinguished from soil reconstitution by the predominant use of exogenous technogenic materials.

Limitations of available studies and identification of research needs

Current research does not allow a complete diagnosis of the effects of soil artificialization on the physico-chemical properties and communities of soil organisms, particularly because it is impossible to break down the contribution of the various land take factors (pollution, habitat loss and fragmentation, sealing; see Chapter 3). The analysis of the available work therefore highlights several points requiring further research.

• Define a common/shared typology of artificial soils that combines uses and a morphogenetic approach, by defining reference frameworks (complete soil profiles) and consider the typology of technogenic materials that make up soils and the history of soil formation. This approach would make it possible to specify the sampling strategy associated with statistical methods relevant to the objective.

• Develop a strong focus on reference conditions (or 'controls'), the choice of which strongly influences the conclusions of studies. The assessment of the effects of artificialization, in particular on soil biodiversity, suffers greatly from the lack of clarification of what the soil conditions and reference land uses are/would be. Knowledge in this area is mainly focused on polluted artificial soils, but relatively little is known about unpolluted soils.

• Systematically incorporate historical data and information with assessments of the physico-chemical characteristics of soils, and give priority to monitoring the temporal dynamics of these properties and biological response patterns over long timeframes. This will provide the means to observe and quantify the impact of land take on soil evolution, to model it, and then associate data on land use, demographic and economic growth, and the classification of uses with these profiles. This requires setting up a research programme to measure the quality of artificial soils. The *Réseau de mesure de la qualité des sols artificialisés* (the Soil Quality Measurement Network) could be a basis for producing databases useful to the scientific community and those involved in soil management. The evaluation of post-development soil 'restoration' practices should be made systematic with a before/after approach in order to provide a basis for the dynamics of artificial soil biodiversity.

• *A priori*, address the question of heterogeneity of measures in order not to 'over-interpret' differences between measures (especially for pollutants) for which the variance is sometimes greater than 200%.

• Continue efforts to link the sources of pollutants in urban environments and their presence in soils subject to this artificialization and thus improve knowledge of their retention time and their circulation in the environment.

• Move from measuring total concentration levels of certain pollutants to characterizing the exposure of target organisms to pollutants via soil and thus assess the risks to ecosystems and human health. Existing studies do not permit such an analysis, although a few address the risks associated with soil ingestion (the greatest risk) by young children.

• Study contaminants other than heavy metals or hydrocarbons, such as nanoparticles or detergents, *in situ*. The effect of the use of pesticides and snow removal salts in cities and for transportation infrastructure is also poorly documented in the literature. The impact on soil organisms of endocrine disrupters (present at increasing concentrations in soils) is poorly addressed. This is also the case for rapidly expanding industrial and mining activities such as the management of electronic waste and the exploitation of unconventional hydrocarbon deposits by hydraulic fracturing processes (which use many chemical compounds, including anti-corrosion biocides).

• Develop knowledge of taxonomic groups other than springtails and nematodes (even if the latter are very representative of their group), such as mites or protozoa. In addition, the concentration of humans (and domestic animals, as a result of interactions with humans) in cities considerably increases exposure to pathogens whose development would be favoured by the urban heat island, and is an emerging issue. The advent of environmental metagenomics could compensate for the lack of specialists for each of the faunal groups by allowing high-throughput analyses of soil biodiversity.

• Explore the effects of the urban landscape matrix. While recent developments have concerned macrofauna, very few studies to date are available for micro-organisms, microfauna and soil mesofauna.

• Develop soil quality indices and functional indicators of artificial soils in order to allow the evaluation of the multifunctionality of soils in land use plans and projects.

3. The direct and indirect impacts of land take on the characteristics and functioning of artificialized environments

THE IMPACT OF LAND TAKE ON THE DIFFERENT CHARACTERISTICS and functioning of artificialized environments can be measured at a broader scales of the landscape, watershed or urban neighbourhood. We will first present the impacts of land take on landscapes, habitats and plant and animal species. We will then examine how it affects urban hydrology and urban stormwater management. Finally, as stated in the introduction to this synthesis, we will review the various indirect impacts on the urban physical environment which, if they can be controlled, may influence the peri-urbanisation phenomena and its resulting land take. These three components in particular concern the urban microclimate, air quality and acoustic environment. As will be seen, these different fields are similar in many respects, particularly the fundamental role of vegetation, which underlines the importance of adopting a multidisciplinary approach to controlling the environmental impacts of soil land take.

Impacts of land take on landscapes, habitats and plant and animal species

IN LANDSCAPE ECOLOGY, A LANDSCAPE IS DEFINED AS an area at a scale of kilometres composed of different types of land use or land cover, arranged in such a way that they may or may not facilitate the circulation of living organisms. Landscapes are therefore characterized by their composition and spatial configuration. The presence of ecological corridors is part of the green (terrestrial) and blue (hydrographic network) systems, promoted in particular by the Green and Blue Frames (*Trames vertes et bleues*) policy implemented in France in 2007 throughout the national territory, including in cities. Conversely, landscape fragmentation corresponds to a distance between habitat patches, the absence of ecological corridors, and barriers limiting the movement of living organisms.

Land take, and in particular the increase in urbanisation, directly affects the surrounding landscapes and habitats by converting habitats into areas dedicated to human activities and by creating linear infrastructure that fragments them. Indirect effects result from socio-economic changes, such as the simplification of landscape mosaics, or by the consequences of changes in the physical environment, such as air temperature or runoff patterns.

Analysis methodology

Habitats, which correspond to the living environments of animal and plant species, are defined by abiotic conditions (soil type, building density), but also by their plant structure (for example, the presence of a tree canopy will be favourable to forest plants requiring shade or to tree-nesting birds), by the presence of resources for species' life cycles (especially food resources for wildlife), or even by their surface area (animals require a home range of varying size depending on the species).

The consequences of land take on biodiversity will be assessed according to composition (proportion of buildings, for example) and landscape configuration (diversity, fragmentation, connectivity, etc.). In general, ecological research considers that environmental factors act as a filter that selects certain types of species. In the case of urbanisation, this environmental filter results from a conjunction of factors acting at the local and landscape levels. Local factors include the formation of very specific habitats (reworked, constructed or sealed surfaces, a high proportion of buildings, gardens) and disturbances linked to anthropogenic practices (introduction of exotic species, mechanical or chemical maintenance of vegetation, trampling, and disturbance). Landscape-level factors, on the other hand, include the isolation of habitats favourable to species and the effect of barriers that hinder their movement.

This filter has a selective effect on species according to their biological characteristics and habitat preferences. Only certain species will withstand modified environments and landscapes, let alone thrive and become abundant, in artificial environments. This selective effect generally results in a decrease in the overall richness and diversity of flora and fauna. However, along urban density gradients, at the interface between agricultural/natural and urban environments, a mixing zone may be observed between two pools of species, those favoured by urbanization and those specific to natural or agricultural environments. This explains why losses of species and functional diversity due to artificialization are not always linked.

One hypothesis arising from this selective environmental filter effect is that of a homogenisation of living communities associated with land take, i.e. a reduction in the variation existing between the various habitats scattered throughout the urban matrix. The final hypothesis concerns the effects of land take on the genetic diversity of species and their reproductive success. It is assumed that high fragmentation of a species' habitat will be detrimental to its mobility and to cross-fertilization between sub-populations. This will lead to relative isolation of sub-populations and a decrease in their genetic diversity. This last hypothesis is generally tested by studies carried out on plant species.

These working hypotheses underpin the analysis of the available results in the literature and guide interpretations.

Effects of land take on habitats, and their fragmentation

Land take fragments and destroys habitats, but can also create new ones

Land take has different forms and timeframes, and affects various animal and plant communities. In general, all articles consider any change from an 'original' land use (natural, forest or agricultural environments) to an occupation by buildings or transport infrastructure to be negative for habitats, in terms of connectivity and landscape fragmentation. However, land take not only leads to the degradation and disappearance of habitats: it also creates new urban habitats such as green spaces, parks and gardens, the roles of which should not be overlooked. The level of habitat disturbance decreases as distance to the city or transportation infrastructure increases. Several articles also mention the difficulty of separating the influence of different variables, particularly those associated with roads (land use, noise, traffic, soil chemistry, for example).

The critical role of habitat connectivity

Three causes of the loss of connectivity have been identified: the decrease in the area of favourable habitats, the increase in the fragmentation of these habitats, and the development of transport infrastructure. All three act as barriers to plant dispersal and animal movement. No positive effects of this infrastructure are mentioned explicitly. However,

Box 3.1. Two threatened tropical coastal ecosystems: mangroves and coral reefs

Mangroves, the coastal forests of the humid tropics, are one of the world's most threatened habitats: they still occupy 170,000 km2 worldwide, but land take, notably through clearing for aquacultural, agricultural and urban development, has reduced their area by 35% since the 1980s. When they were regarded as unhealthy environments, these semi-aquatic areas were widely used for the disposal of various materials and waste, which could lead to their progressive filling. Remaining mangroves are at risk from forestry, agriculture and aquaculture. In addition, the decrease in fresh water inputs and their quality (pollution, salinity) leads to their decline. However, urbanization, tourist and residential development and industrialization are the main factors contributing to their deterioration.

Coral reefs are also threatened ecosystems: in the early 2000s, 30% of the world's 300,000 km^2 of coral reefs were considered degraded, and their area had reduced by 10% in a few decades. Coral reefs are the object of direct destruction, either through mining or by their smothering during developments such as the construction of ports or marinas. Particularly sensitive to turbidity and water pollution (fluvial and coastal), corals are also affected by all types of development as well as tourist traffic. In Tahiti, erosion linked to construction in very steep areas leads to hyper-sedimentation of lagoons and to suffocation of fringing reefs. In Mayotte, the intensification of erosion and the rapid retreat of mangroves have strongly contributed to the silting up of the lagoon since the 1980s.

fragmentation is not directly proportional to the size or prominence of the infrastructure concerned. The effect of transport infrastructure is not only structural (fragmentation), but it also causes physical and chemical changes in the surrounding environment.

In addition to land use, spatial configuration is important. For an equivalent area of lost habitat, the effect on the loss of connectivity between patches of favourable habitat will vary, depending on the density of the areas of habitat, the distance between them and the presence of linear landscape features such as corridors, for example.

Effects of land take on plant species and communities

The strong influence of local environmental conditions on vegetation

Plant species are more strongly influenced by local environmental conditions (e.g. the density of buildings observed at the site of a floristic survey) than by the landscape configuration. This is explained by the fact that plants are immobile, they are strongly affected by the conditions of the location where they are established, and are even used as indicators. However, they also depend on landscape parameters, which may or may not facilitate the dispersal of their pollen or seeds, regardless of whether this dispersal is via wind, water or fauna, which themselves depend on the landscape configuration. Environmental conditions and, in particular, soil type, remain an important determinant of species assemblages, including within highly artificial habitats such as urban environments.

Selection in favour of exotic and generalist species

Almost all studies examining not only the number but also the type of species present or their abundace concur that the selective effect of urbanization density, whatever the context, favours exotic (or neophyte, invasive) species and conversely disadvantages native, archaeophyte[7] or rare species. This selection is expected, since some exotic species have been introduced intentionally, for their aesthetic or functional qualities, especially in cities. The same is true along transport infrastructure, exotic species being favoured up to 150 m away in grasslands, and only 10 m away in forests, confirming the greater vulnerability of herbaceous ecosystems to land take.

The degree of specialisation of plant species is also analysed: artificialization thus appears unfavourable to species associated with a natural habitat, such as wetland (hygrophilic) or forest species, or species with low nutrient requirements (oligotrophs). Conversely, species that spontaneously grow on uncultivated land and on paths (ruderal) that benefit from nitrogen enrichment of the soil (nitrophilous) are favoured, as are plants derived from bulbs or rhizomes (geophytes) due to mowing.

Ultimately, these studies broadly validate the selection hypothesis, with generalist species being favoured in most studies, but more mixed results for specialist species. The presence of favourable habitats, such as wasteland or green spaces, tends to favour

7. Archaeophytes are species introduced before 1500.

floral richness in general. Under certain conditions, specialist species that are normally found in natural habitats, and threatened in agricultural and unused areas surrounding cities, may be present in cities when these habitats have been preserved. However, the link with agricultural intensification has not been considered in this analysis. Indeed, in most of the articles, where agricultural areas are included, the level of intensity of agricultural practices is not specified. In addition to the degree of urbanisation, larger and older cities, and those with a greater fragmentation of habitats, would favour generalist species over specialist species. Conversely, a configuration with fairly large habitat fragments, ecological connections and surrounding undeveloped landscapes will have a favourable impact on all species except generalist species.

Contrasting overall effects on the entire flora

A significant number of studies have been unable to reach a conclusion on the effects of artificialization on plant species. These more ambiguous results are obtained in studies testing the role of artificialisation on the entire flora, rather than on particular species or habitats. Thus, floristic richness is sometimes adversely affected, and sometimes independent from the degree of urbanisation or other human disturbances. Some studies highlight the greater floristic richness of cities, particularly at average levels of urbanization (as opposed to fauna). This could be explained by the combination of both indigenous and exotic assemblages, but also by a positive effect of spatial heterogeneity causing a decoupling of the negative effects of artificialization on specific and functional diversity.

Where exotic species play an important role in cases of increased floristic richness, the results tend to invalidate the hypothesis of floristic homogenization. Some studies comparing a large number of urban centres using two vegetation surveys over time show long-term homogenization effects, particularly due to ubiquitous exotic species, whereas others indicate no effect or only partial homogenization.

With regard to the hypothesis of lowered genetic diversity of a species linked to habitat fragmentation, the available studies show variable results, and the small number of available studies does not allow this hypothesis to be validated.

The important role of interactions between plants and animals

Biotic interactions between plant species on the one hand, and between plant and animal species on the other, are generally an indicator of the healthy functioning of natural ecosystems. They can be observed in some semi-natural urban habitats. In addition to their effect on the reproductive success observed at a species level, in certain habitats, such as wastelands, the species significantly associated with them are entomogamous, i.e. pollinated by insects, the circulation of the latter being facilitated by the connectivity of this habitat along abandoned transport infrastructure. Similarly, there may be a correlation between the floristic richness and that of certain animal groups in these habitats (Table 3.1).

Table 3.1. Average index of the effect of land take on fauna and flora biodiversity and total number of results analysed

Form of land take	Types of organisms	Effects on biodiversity: Species richness	Presence and Abundance	Select for generalists	Select for specialists	Diversity (genetic, ecosystem, landscape)	Demography	Total number of results
Poor habitat quality, disturbances	Flora	− 0.8	1	0.8	0			12
	Fauna	− 0.9	− 0.8	0.5	− 1			24
Urbanisation with dense human populations	Flora	− 0.1	0.3	0.8	− 0.2	− 0.7	− 1	59
	Fauna	− 0.7	− 0.1	0.7	− 0.6	− 1		198
Transport infrastructure, industry, mining	Flora	− 1		0.9	− 1			7
	Fauna	− 1	− 0.9	0.5	− 0.8		− 1	45
Intermediate level of urbanization	Flora	0.4		− 1	0	− 1		28
	Fauna	− 0.1	0.4	0.5	0.7			86
Favourable urban habitat (wastelands, green spaces)	Flora	0.8	1	0.6	0.9	− 1		30
	Fauna	0.4	0.1	0.5	0.1			28
Size of the city, fragmentation of landscapes	Flora	0	− 1	0.3	− 1	0.2		14
	Fauna	0	0	1.0				9
Diversity, habitat connectivity	Flora	0.9		− 0.2				16
	Fauna	0.8	0.6	1	0.5	1	− 1	46
Total number of results		319	101	78	94	30	16	638

Each effect is expressed as an index between -1 and +1, depending on whether the effect is negative or positive, and 0 if no effect is detected. The indices are then summed by groups of organisms (flora and fauna) and by land take type, and divided by the corresponding number of results. An index close to 1 (green cell) corresponds to generally positive effects observed throughout the analysed literature, while an index close to zero (yellow cell) indicates no effects, or compensation between positive and negative effects depending on the case. An index close to -1 indicates generally negative effects (red cell). A comparison of the effects of land take on plant and animal organisms suggests that wildlife is more vulnerable. This trend is confirmed for the impact of urbanization on the species richness, which is more negative for fauna (index of -0.7, calculated on 129 results) than for flora (-0.1; 22). Conversely, the impact of favourable urban habitats is more positive for the richness of flora (0.8; 13) than for fauna (0.4; 8). Urbanization also has a negative effect on the diversity of fauna and flora (-0.8; 19). Poor habitat quality also has a more negative impact on wildlife (-1; 10) than on flora (-0.7; 9). Intermediate urbanization levels are more favourable to floristic (0.4; 13) than faunal richness (-0.1; 66), although this is offset by a greater abundance of fauna (0.4; 10).

The effect of land take on animal species and groups of species

Overall, negative but complex effects

Land take generally has a negative effect on animal organisms. However, this result masks large disparities between studies of different scales, taxa and ecological groups, as well as the degree of artificialization.

The density of human settlements and buildings thus has a negative effect on species richness, but a weakly positive effect on the presence and abundance of arthropods, mammals and birds. Local conditions (pollution, disturbance, disruption) have a negative effect on all faunal biodiversity parameters. Some species are particularly sensitive to the proximity of human activities (grey wolf, puma, lynx, and prairie dogs). High quality habitat is favourable to specialist species and less suitable for generalist species, with the opposite the case for urbanization. Mammals are the group least affected by urbanisation, but while certain larger generalist or domestic species are favoured by urbanisation (red fox for example), the opposite is true for large predators (lynx, grey wolf, puma etc.). The presence of green space is favourable to the presence of mammals in urbanised environments and to their movements between areas of favourable habitat, and it limits the extinction of threatened species. The same is true of cultivated areas and wetlands in urbanised areas.

Together with changes in land use, the configuration of the landscape also affects animals. According to the theory of environmental filters, artificialization at a landscape scale more strongly affects small faunal species that have reduced dispersal capacities and are mostly ground-dwelling. The greater the affinity of organisms for agricultural or forest habitat, the more they will be affected by the destruction of these habitats. The impact of fragmentation is greatest for species with low dispersal capacity and forest species or for specialist species (e.g. flightless carabid beetles). The effects of artificialization and fragmentation are specific to each animal species. For example, they are relatively neutral for birds, favourable for raccoons, and negative for green frogs or white-tailed deer. Conversely, habitat connectivity facilitates the movement of individuals and promotes the sustainability of populations of all organisms. In conclusion, we observe complex fragmentation effects on fauna, but they are clearly negative beyond a certain artificialization threshold.

Increased animal interactions

Urbanization and fragmentation of natural habitats also tend to increase the number of interactions between animal species, and this is unfavourable to the most specialized species due to competition with generalist species for resources. These effects are commonly displayed for large wildlife, whose food requirements are high. They are also noted in studies of former mine sites, where reduced resource availability is a limiting factor. Interactions are also exacerbated by the disruption of normal daily activity patterns due to avoidance of human activities, potentially leading to the co-presence of competing animal species at the same time of day. The urbanization effect of increasing potential faunal interactions is related to habitat loss and the presence of animal species in areas of high human occupancy and domestic animals that also pose a danger. In addition, the barrier and pathway effects of human infrastructure push animal species to use the same routes along which to travel.

Threshold effects

Low to medium levels of fragmentation increase the heterogeneity of the landscape (and thus the diversity of habitats over a given area), but above a certain threshold, the effects become predominantly negative, and this for very different organisms. Higher species richness, abundance or proportions of specialist species are detected at average levels of urbanisation.

We observe consistent results among studies dealing with animal and plant species. On the one hand, that generalist animal species and exotic and ruderal plant species are favoured by urbanisation, thus illustrating the environmental filter effect, while the connectivity of landscapes is favourable to fauna and flora. In contrast, studies conclude that the negative effects of artificialization on fauna are greater than on flora, particularly because of the density of urbanisation, to which fauna is more sensitive than flora.

Some work has attempted to integrate the effects of climate change by sampling at different altitudes or by simulations. They show significant negative effects of the temperature factor and the density of the built environment, and their convergent effects on certain species.

Specific effects of road and rail infrastructure and mining areas

Transport infrastructure, industrial and mining areas generally have a negative effect on flora and fauna, however, birds are less affected than other organisms. Road infrastructure has an amplified effect in relation to its footprint and traffic. Forest roads, even with little traffic, can represent significant interruptions because they are located in habitats that are still preserved. These roads can also lead to changes in land use and disturbances. Roads are generally unfavourable to animal movement, and a motorway can represent a complete barrier. Roads are also associated with increased wildlife mortality due to vehicle collisions.

Railways can be either an obstacle or a habitat. They can also act as movement corridors and thus promote the dispersal of individuals. The presence of wooded vegetation may also favour the presence or movement of certain species in the vicinity of roads. The negative impact of transportation infrastructure can be mitigated by the construction of crossings and certain landscape features.

Transport infrastructure, including roads, is also often associated with human activities and/or presence that can alter the behaviour and life history of animal species.

In mining areas, a primary finding is that animal species are generally less numerous. The disturbance of the original environment by mining operations is significant and of different kinds (forest cutting, soil pollution etc.). The impact of their rehabilitation and, in particular, their conversion to the natural environment has been studied. The recolonization of these areas by animal species is generally observed, however it can occur at different rates depending on the species: the animal species present are chronologically linked to the stages of recolonization by plant species.

Summary

In general, while analyses of changes in the shape of artificial landscapes converge on an alarming diagnosis as to their potential consequences on habitats and biodiversity, there is also great variability in their spatial arrangement depending on the case studies. The results are linked to the way biodiversity is measured (richness, abundance etc.), and to the groups of species on which researchers focus their attention. Even for hypotheses that appear to be very sound and confirmed, such as that of biotic homogenization, there are studies that provide subtly different or even contrary results. The results therefore present a certain complexity, with combined or opposing effects from certain factors. However, the value of certain habitats, such as gardens or wastelands is widely stressed, as is the consideration of private land in the identification and preservation of ecological networks. Encouragement of heterogeneity of building heights and plant strata is favourable to the abundance of birds in a dense city. Another regularly stated management objective is to maintain connectivity between favourable habitats by constructing wildlife crossings or developing ecological corridors of a certain width (>20 metres).

In addition to the expected environmental impact of green belts on biodiversity, we must not forget the benefits they can bring in terms of quality of life. One tool long used by developers to limit urban sprawl has been greenbelts; the width and location of these belts are crucial to their effectiveness. The concept of ecosystem services is also being used to demonstrate the economic and cultural value of green spaces and urban green spaces. A mechanism delimiting the extension of subdivisions and the areas to be preserved, combined with a mechanism to compensate for permeable soil losses, could be proposed. The notion of resilience of the urban 'environment' could also be applied, by combining several principles of urban development and planning, taking into account the morphology of cities and their natural and cultural diversity: reducing land consumption, implementing a green matrix, encouraging non-motorized transport, protecting cultural and rural heritage, and designing compact city models.

The effects of urban density thresholds demonstrated by studies focusing on species and groups of species should be further integrated into proposals that place particular emphasis on limiting urban sprawl. This policy of limiting sprawl, which has many advantages (limiting losses of agricultural and forest land, reducing the carbon impact of cities by reducing travel), should be accompanied by measures designed to limit, or compensate through specific developments, the effects of urban densification in the heart of urban areas. The results show that a trade-off is necessary between reducing artificial areas, which can increase impacts on biodiversity, and developing open landscape mosaics, which are more favourable to biodiversity but require more space.

Limitations of available studies and identification of research needs

Unfortunately, there is some disconnect among studies of habitat loss, landscape changes and their effects on living organisms. Similarly, among the studies dealing with living organisms, few deal jointly with plant and animal species of different kinds while taking soil characteristics into account, with the exception of literature reviews. This disconnection is probably linked to the differing specializations of researchers, however a multidisciplinary and multi-taxon approach would be desirable. Such studies would be valuable in guiding decision-making, given that a certain landscape change will have a specific effect on a certain plant or animal species. The participation of the humanities and social sciences would be highly desirable in order to consider the perception of biodiversity by various groups (inhabitants, city gardeners, etc.), and in order to better guide recommendations. The production of maps or plans that combine this information (landscapes, effects on organisms, perceptions of stakeholders and users) would be a bonus.

There is also a lack of long-term monitoring and population viability studies. This is particularly true for fauna, whereas flora has been studied for a longer time, thus allowing for temporal comparisons. Similarly, plant studies concern more varied biogeographical domains, or in some cases compare a significant number of cities on a national or global scale, whereas studies on fauna are often location-specific. The latter would benefit from being extended geographically in order to compare the effects of land take between localities by strictly applying the same methodologies. The same observation applies to studies which, based on a case study, put forward proposals for spatial planning and management of species that are likely to mitigate the negative effects of land take. Studies testing the relevance of these recommendations simultaneously in several cities would make it possible to measure their effectiveness according to different parameters (socio-economic and cultural contexts, bioclimatic domains, and urban models) and to better guide decision-making.

Finally, it is important to better distinguish the direct and indirect effects of fragmentation: in the majority of studies, the effects of fragmentation are derived from the results of the effects of changes in landscape composition (mainly increases in artificial surfaces around sites, buildings, roads, etc.), whereas few studies analyse the direct effects of fragmentation and connectivity in a narrow and specific manner (minimum width of a corridor, maximum distance between two habitat patches that can be crossed by a species, etc.).

Impact of land take on urban hydrology and stormwater management

Urbanization as a determinant of soil artificialization is the most important factor in modifying hydrological functioning, since it greatly increases runoff flows and the resulting risk of flooding[8]. It also affects the quality of run-off water, which accumulates pollutants when it comes into contact with certain materials. Urban water management in town planning operates at the urban watershed scale, but to control what happens at the watershed outlet, it is necessary to assess processes at the neighbourhood and structure scales. These different scales are therefore reflected in the literature review. This section primarily includes elements from a study commissioned in 2015 by the *Conseil général de l'environnement et du développement durable* (CGEDD).

The development of sewerage systems dates back to the 19th century. To transport wastewater out of the city, town planners and engineers chose to use the existing stormwater drainage network (the so-called unitary network option). Wastewater treatment became widespread in the second half of the 20th century, accompanied by separate networks for wastewater and stormwater. However, it was not until the 1970s and 1980s that the technical and environmental problems resulting from the rapid transfer of rainwater to the natural environment, such as pollution peaks linked to direct discharges into the natural environment during rainy events and urban flooding, became clear.

An initial response involved the creation of centralized rainwater storage and settling facilities. More recently, the option of controlling rainwater at the source, known in France as 'alternative techniques' (as opposed to 'all-pipe'), has emerged. This development marks a turning point in urban water management, by reintroducing the various components of the water cycle, particularly infiltration. At the same time, urban water is once again becoming an environmental asset and an amenity. Major efforts are being devoted to the restoration of urban watercourses.

Impacts of land take on hydrology

Impacts on hydrological processes

Changes in surface and soil processes

Rain that falls on impermeable urban surfaces (roofs), or coated/sealed (roads, car parks etc.) primarily generates surface runoff, to the detriment of infiltration and evaporation. In the presence of wind, vertical surfaces intercept some precipitation (not quantified). However, the infiltration on coated/sealed surfaces is not always negligible due to the porosity and roughness of these surfaces, and evaporation from these surfaces remains significant in terms of the overall annual supply (10 to 25% of rainfall). The artificialization of urban soils modifies the structure and texture of the soil (see above), so that the temporal and spatial dynamics of infiltration and sub-surface runoff are more strongly conditioned by the effects of artificialization than by the initial characteristics of the soil.

Water flows in the shallow subsoil are also modified by the effects of the multiple networks that run through urban soil. On the one hand, leaks from drinking water supply

8. This ESCo does not address the issue of the vulnerability to river or coastal floods of structures located in vulnerable areas, the determinism of which goes far beyond the issue of soil artificialization, and which are, moreover, already heavily constrained by existing regulations.

networks can sometimes be a significant source of groundwater. On the other hand, the sewerage networks and the trenches in which they are laid contribute to the drainage of water from the ground and sometimes evacuate very significant volumes (from 20 to 30% of the annual rainfall in Nantes). Wastewater seepage into the ground also occurs. Finally, the presence of groundwater extraction to supply urban needs and the lowering of the water table in the vicinity of underground infrastructure (car parks in particular) also affect the levels of underground water tables.

A variety of situations at the catchment scale

Watersheds affected by urbanization present a wide range of conditions, from partially urbanised watersheds or watersheds in the process of urbanization (peri-urban) to watersheds that are totally urbanised and equipped with a rainwater drainage network. A catchment area can be characterized by a runoff coefficient, defined as the proportion of rain that turns into flow at the outlet during a rain event. During normal rainfall events, this coefficient is often significantly lower than the proportion of impervious surfaces. Its value increases with the magnitude of rain events, sometimes exceeding the waterproofing coefficient.

The influence of urbanization on the hydrological regime of small rivers should theoretically translate, in an urbanised or urbanizing watershed, into an increase in flood flows and mean flows, and a decrease in low water flows[9]. Observations in the field lead to less clear-cut conclusions; the particularities of each catchment area and its drainage network remain crucial.

It has long been recognized that urban development necessarily results in a reduction in the recharge of shallow water tables, and therefore in a drop in their level. Recent scientific literature reports more contrasting examples of falling but also rising groundwater levels. The complexity of the processes involved, the lack of observations as well as the importance of the scale considered, means that we should take these results with caution.

Land take also affects evapotranspiration, but in urban areas this is still poorly documented. Its measurement is infrequent, due in particular to the methodological difficulty of transposing methods developed for large areas of homogeneous vegetation to very heterogeneous urban areas. It is therefore often estimated by modelling without proper validation of these results. Evapotranspiration would, however, represent a significant part of the annual water balance, from 30% to nearly 60% of the annual rainfall for catchments with 35% to 60% of their surface area sealed.

Impact on stormwater quality

Urban infrastructure (pavements, safety equipment, street furniture), roads, buildings or the commercial and industrial activities that take place there, and automobile traffic, are likely to emit a wide variety of pollutants, which are found in stormwater runoff. Special attention is paid in the literature to urban wet weather discharge (UWWD): this

9. Minimum flow of a watercourse.

term refers to direct discharges to the environment of effluent from combined sewerage systems, which take place during very intense rainfall events that overload wastewater treatment plants. These UWWDs therefore contain the pollutants present in both rain-water and wastewater.

Characterization of stormwater runoff

Recent research on runoff water, carried out within the framework of the French Observatory for Urban Hydrology (Urbis network), confirms the presence of many classes of pollutants (Box 3.2). The transfer of rainwater loaded with pollutants in the networks concentrates, at the outlets of catchment areas, pollution resulting from the mixing of effluents from areas with various land uses. The contamination of rainwater with polycyclic aromatic hydrocarbons (PAHs), nonylphenol (NP) and certain trace metals can, however, be significant at the parcel scale, with strong variability between rainfall events.

In rainwater, some pollutants are transported mostly by particles (over 90% of PAHs, over 80% of lead and chromium), but others are dissolved (zinc and alkylphenols) or distributed between the two fractions (copper, light PAHs etc.). This observation reinforces the value of managing rainwater by infiltrating a significant part of the volume of runoff as close to the source as possible to treat the dissolved pollution, and not limiting the treatment to settlement. Managers are confronted with the problem of contaminated sediments at the bottom of structures. The mobility of pollutants trapped in these materials depends on many parameters: geological context, physico-chemical conditions, underlying groundwater levels, etc. The vegetation within the structures also influences transport, and microorganism assemblages in the facilities are highly dependent on water quality in the structures.

Box 3.2. Data on rainwater contamination from the ANR project 'Innovations for Sustainable Urban Water Management' (INOGEV)

This study focused on three urban catchment areas (the Paris region, Nantes and near Lyon) that are equipped with separate networks and represent different types of land use (detached housing, residential with apartment buildings and individual housing, and industrial). This produced new information on the effect of land artificialization on the quality of water runoff:

- Concentrations of metals originating from buildings, roads and human activities (arsenic, cobalt, molybdenum, platinum, strontium, titanium, vanadium), which have rarely been tested for in urban runoff, were measured. Most concentrations measured in runoff exceeded environmental quality standards.
- Many pesticides are still detected in stormwater.
- The first experimental data on PBDE (polybrominated diphenyl ether) levels in rainwater were obtained, with BDE-209 present at much higher levels than those in atmospheric deposition.
- Bisphenol A and alkylphenols are present mainly in a dissolved form, and are therefore mobile.

Impacts of stormwater discharge on aquatic environments

The impacts of traditional pollutants (suspended solids, or SS, nitrogen and phosphorus) brought about by stormwater discharges or urban wet weather discharges have been studied for many years. Discharges of SS can have direct clogging effects on the riverbed, while the oxidation of suspended solids leads to a decrease in dissolved oxygen concentration in the water, which can lead to fish mortality. Suspended solids also act as the vector of pollutants present in the particulate phase. Nitrogen and phosphorus discharges into aquatic environments with very slow or relatively closed flows (lakes and urban streams, some bays) contribute to eutrophication.

The assessment of the impact of direct rainwater discharge on the natural environment highlights the potential toxicity of metals (chromium, lead, copper and zinc) and organic substances such as nonylphenols, organotins, polychlorinated biphenyls (PCBs) and PAHs to the aquatic environment. Concentrations of metals, PAHs and organic micropollutants in aquatic environments are significantly increased by stormwater discharges. On an event-driven scale, stormwater discharges are significant and sometimes major contributors to urban discharges compared with discharges from wastewater treatment plants, particularly for emerging pollutants such as alkylphenols, bisphenol A or certain phytosanitary or pharmaceutical residues. A study in the Paris region suggests that, in the case of alkylphenols and bisphenol A, rainwater could contribute 20 to 60% of the annual pollutant flows in the Seine area.

Stormwater discharges have significant impacts on aquatic ecosystems. A certain number of substances (pesticides, certain metals), can cause bioaccumulation and biomagnification along trophic chains, which can affect some organisms (disease, lower life-span, impaired reproduction), or eventually lead to the disappearance of certain species. The many organic micropollutants that have been more recently observed in rainwater have consequences for aquatic environments that are still very poorly understood.

Finally, stormwater discharges, and especially urban wet weather discharges, have significant health impacts.

Alternative stormwater management systems

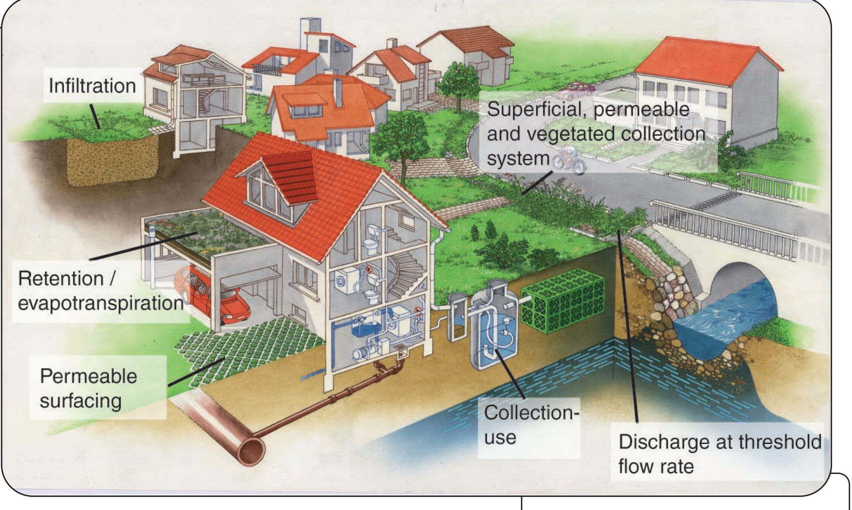
In contrast to the rapid drainage of rainwater, which has long dominated stormwater treatment, new approaches have been developed over the last twenty years. The objective is to ensure that urbanization disrupts the water cycle as little as possible, and in particular minimizes surface runoff. In France, these are ‘alternative techniques’ or ‘compensatory solutions’ (from the effects of urbanisation). They are evolving towards devices integrated into urban design that help to make the city more permeable, and restore nature's place in the city. Managing rainwater at the source is one of the main tools for controlling the hydrological impacts of land take.

The various available measures

Centralised structures, supplied by pipeline networks, consist of underground retention basins in city centres and open-air basins in peri-urban areas. Most of these systems are based on settlement processes.

Management techniques at the source rely on the storage and infiltration of rainwater, captured as close as possible to the source in order to reduce runoff but also the associated pollutant flows. Different devices are being developed (Fig. 3.1): gullies (shallow, wide, vegetated ditches), vegetated roofs, 'rain gardens' (planted depressions created to recover excess runoff from a building and its environment), reservoir pavements (porous structures with a high water retention capacity), infiltration trenches (along car parks or pavements), biofilters, etc.

Figure 3.1. Stormwater management at the source.



From Bayerisches Landesamt für Umwelt.

Hydrological performance of source-based management systems

At the local scale, the hydrological performance of the various devices has been the subject of numerous studies, often devoted to observation of their operation. Most of the structures are designed to limit peak flows in order to control sewer overloads and flood risks. They are therefore designed to protect against exceptional events, but also, sometimes, to reduce the volumes discharged during normal or heavy rainfall. Performance is assessed based on the reduction or delay in peak flow, volume reduction, or retention capacity. There is consensus on the effectiveness of the devices, although there is considerable variability in performance. Continuing efficacy over time, however, depends on the infiltration capacity of underlying soil layers and upkeep of the facilities.

At a broader scale (catchment, urban river, aquifer), these systems play a beneficial role in principle, but their presence at the urban scale must be systematic enough for this impact to be significant, which is not yet the case. They are likely to influence three components of the urban water cycle: groundwater recharge, urban river baseflow, and to a lesser extent evapotranspiration. Few studies show the real impact on groundwater quantity and baseflow by the general use of these techniques. Although diffuse infiltration of rainwater into green spaces is likely to promote evapotranspiration, it would appear that 'rain garden' type devices have a limited effect on this component.

The limits of these systems and the obstacles to their development are often linked to the risk of hydrological malfunction in the medium or long term. The two problems raised here are: sediment trapping, the management and treatment of which is little addressed upstream, and clogging, which reduces infiltration. However, there are now recommendations on strategies to reduce the risk of clogging, and vegetation plays a role in this. Geotechnical or geological risks (proximity of buildings, nature of the subsoil) are sometimes highlighted in relation to infiltration practices, but few studies have focused on these topics.

The environmental performance of the various systems

Centralized downstream structures provide efficient removal of particulate contaminants and reduced bioavailability of metals (through interaction with sediments). The use of extensive centralized filtration structures (planted filters) is developing in France, but the treatment of polluted sediments that accumulate in these structures is a serious concern for communities. For centralized infiltration structures, studies confirm the role of soil in trapping the main pollutants carried by rainwater (heavy metals, hydrocarbons, etc.) and present mostly in particulate form. However, there is the issue of pollutants in dissolved form, such as pesticides, which are detected downstream of centralized infiltration systems.

At-source management systems allow differentiated management of runoff water, and are adapted according to its contamination potential. The reduction of pollutant flow is promoted by the fact that the leaching and entrainment effects of particles are lower on upstream surfaces (lower flow rate). Permeable surface coatings show a capacity to reduce the concentrations of suspended particles and limit PAH inputs. Vegetated permeable surfaces allow pretreatment of surface runoff by settling and filtration through vegetation. The infiltration of normal rainfall into permeable, vegetated retention structures considerably reduces the annual pollutant flow: these structures (bioretention, rain gardens) ensure the physical filtration of particulate pollutants through the filter substrate and the sorption of dissolved pollutants. However, the potential for pollutant transfer to the subsoil of the infiltration systems must not be overlooked.

Limitations of current studies and identification of research needs

Urban hydrology is defined as the science of the water cycle in an urbanised environment from the physical, physico-chemical and biological perspectives. It includes the study of the interactions between the water cycle and human activities in this environment. It has developed along these lines by closely associating research, engineering and operational practices, which constitutes a richness and originality. Research priorities have responded to or anticipated needs: rainwater drainage, protection against urban flooding, development of alternative stormwater management techniques, and protection of aquatic environments. The contribution of water and vegetation to the living environment, the reduction of urban heat islands and the integrated management of urban water are now key concerns that reinforce the crucial role of the water cycle in urban development.

Monitoring for research. The development of urban hydrology monitoring started with the creation of the URBIS Observation and Experimentation System for Environmental Research. It is important to continue with and strengthen this initiative, which must integrate the oversight of practices and governance.

Integrated hydrological modelling. Management at the source, and the roles of infiltration and vegetation, illustrate the involvement of all hydrological processes in stormwater management. There is a genuine need to develop knowledge of hydrological processes that have hitherto been little studied in an environment with unique characteristics: spatial heterogeneity of the soil and subsoil, and diversity of land use. It will thus be possible to develop a new generation of models at different scales – the local system, catchment area, and urban agglomeration – meeting the following needs: design and size of management systems at the source, integrated modelling of urbanised and peri-urban catchment areas, and combined modelling of water, pollutant and energy transfers in urbanised environments.

All of the functions of urban water management systems can only be studied within the framework of interdisciplinary projects that bring together different aspects (hydrology, the functioning and evolution of the city, and anthropogenic actions). Research must involve different scientific communities, including those of the spatial and environmental sciences, engineering sciences, and the human and social sciences. This interdisciplinarity also makes it possible to study the role of the stakeholders involved in design, maintenance and even rehabilitation, with the aim of creating new guidelines and helping local authorities to review their organisational structures.

Conclusions

Soil sealing and the presence of underground networks and structures strongly influence the water cycle in urbanised areas at both a local and broader scale. Artificialized soils, except for sealed surfaces, can also have an impact on water availability for vegetation at the local scale due to compaction, or strong spatial heterogeneities of texture or structure. Coated soils also promote the deterioration of urban runoff water quality through the transfer of pollutants emitted by human activities.

The proposed policy instruments are based on the regulation of ‘rainwater and runoff’ by unitary and separated systems, and are aimed at the development of both centralized structures and management systems at the source. They would form a component of multifunctional urban developments: reintroduction of nature into the city, insertion of green and blue spaces, organization of space and greening of neighbourhoods and parking areas, and *a priori* conservation of biodiversity. The integrated management of urban water reinforces the structuring role of the water cycle in urban planning and offers new perspectives, with increased needs in terms of monitoring and integrated models. Asset management as regards structures and facilities is also a new field of investigation for research, based on studying the role of stakeholders involved in design, maintenance and even rehabilitation, with the aim of helping local authorities review their organisational structures.

Impacts of artificialization on the physical urban environment

Here, we focus on the consequences of artificialization on the urban microclimate, the acoustic environment and air quality, which mainly result as indirect effects of artificialization.

The study of the impacts on the global climate would be relevant, but it is very complex and goes far beyond the framework of this ESCo: it should include a complete overview of the impacts of all local activities on climate change as well as the feedback from these climate changes on the local area, as well as many other impacts (air pollution, economy etc.). It would also require the development of approaches relating to the urban metabolism[10] and its place in the carbon balance (GHG emissions created and avoided, sequestration, etc.).

The impact of artificialization on the physical environment can be direct, due to changes it brings about in the surfaces, and indirect via the uses that it permits or encourages. The processes involved and their impacts are studied, on the one hand, at the scale of simple surfaces, and on the other hand, at the scale of buildings, streets, to the scale of the city (neighbourhood, town, agglomeration). Changes in surface conditions, sprawl, and densification processes will be addressed in terms of their impact on thermal and acoustic amenity within cities.

Impacts on the urban microclimate

Cities are characterized by a specific microclimate due to the nature of urban surfaces (mainly mineral), their shapes, and human activities. The specific nature of the urban

10. Urban metabolism is defined as all of the transformations and flows of matter and energy that occur in the life cycle of an urban area. (Bochet and Cunha, 2003).

microclimate is known as the urban heat island phenomenon, or UHI (higher temperatures in the city than in neighbouring rural areas). In addition to its negative impact on comfort in urban areas, the UHI phenomenon leads to health issues with sometimes dramatic consequences, such as during the heat wave in the summer of 2003, which resulted in an estimated 70,000 excess deaths in Europe, including 20,000 in France.

Microclimatology research in recent years has focused on the influence of urban densification and soil artificialization on the urban microclimate and on ways to mitigate its effects, particularly vegetation-based solutions, but also the possibilities offered by urban materials and designs. The literature reviewed essentially uses 'process modelling' approaches; some studies refer to programmes for measuring the parameters describing the microclimate, but these remain limited.

Principles for the study of urban climates

The urban climate results from energy (radiative, thermal) and water exchanges between surfaces and the atmosphere, and from aerodynamic interactions between surfaces and the atmosphere which occur at very different scales in both space and time within the urban boundary layer[11].

The water balance (Fig. 3.2.A) reflects the exchange of water between the soil and its underground networks, surfaces and the atmosphere during periods of rainy or dry weather, and takes into account the spatial variability of ground surface characteristics (impermeability, presence of vegetation), the hydrodynamic properties of the soils (permeability) and the presence of underground networks that form preferential drainage routes in the soil. The evapotranspiration flux between the surface and atmosphere corresponds to a heat flux, known as the latent heat flux.

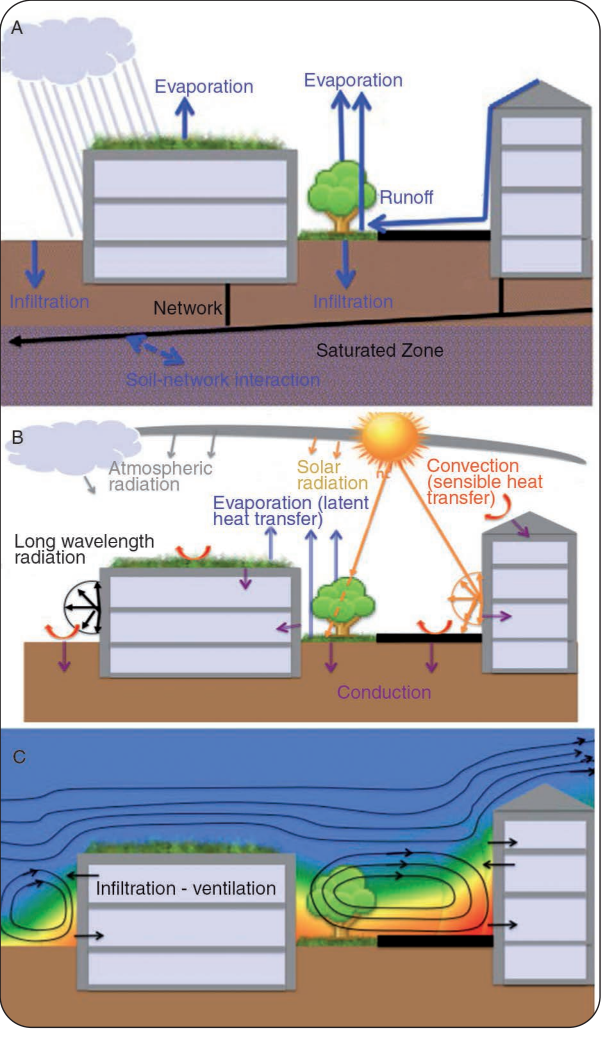
The energy balance (Fig. 3.2.B) represents the balance between net radiation, latent heat flux, sensible heat flux (convection at surfaces) and heat flux stored by conduction in the soil and through the building envelope.

Aerodynamic interactions between the canopy and atmosphere result from aeraulic phenomena, i.e. processes that describe air flows (Fig. 3.2.C).

The nature and properties of the soil play a role:
- via permeability (water runoff or infiltration, storage in the soil, evaporation and evapotranspiration);
- through optical characteristics (albedo, transmissivity, emissivity) and thermal characteristics (conductivity, heat capacity and density), in the heat balance via the absorption or reflection of radiation;
- through surface roughness, which affects air flow, but also by the air/surface temperature difference, which is an indirect effect of the heat balance.

11. Human activities in urban areas create an urban boundary layer, influencing, among other things, thermal conditions (according to Britter and Hanna, 2003).

Figure 3.2. Water balance (A), thermo-radiative balance (B), and aeraulic processes (C).



Measurement and modelling of the urban heat island

The assessment of spatial temperature differences within an urban area is carried out by measurement and modelling. This can provide access to ground surface and atmospheric heat island data.

UHI methods of measurement and data analysis

Surface temperatures in urban areas are mostly measured by remote sensing. To characterize urban heat island (UHI) atmospheric conditions, in-situ measurements are used, which are carried out using sensors placed in the urban environment (Fig. 3.2.c) that record air temperature, humidity, wind speed and direction, and heat fluxes.

The analysis of the data acquired by measurement can be done with empirical geoclimatic regression models, which aim to establish a statistical relationship between temperature and one or more explanatory variables depending on the phenomena involved (population, urban form, land use etc.). It can also be carried out using geoclimatic classification methods, which aim to identify climatically homogeneous zones as a function of the built density and height of buildings or, for undeveloped areas, the nature of the surfaces, or by using geostatistical interpolation methods. The resulting thermal maps of the city make it possible to study the relationship between the change in the magnitude of the UHI and the development of urbanization by analysing historical datasets.

Climate modelling approaches for urban heat islands

The last decade has seen major advances in the development of climate models based on the spatial representation of the city and on the simulation of energy and water exchanges between the urban environment and the atmosphere to describe the UHI phenomenon. Urban climate models can be classified into two broad types, according to the scale of assessment: the urban fragment (from the street to the neighbourhood) or the city.

Models at the scale of the urban fragment ('thermal ambiance' approaches) aim to study the heterogeneity of the physical environmental factors that contribute to the comfort of the city dweller. At the scale of the surrounding environment (street, square, etc.), they explicitly represent (geometry, positioning) the various elements of the urban environment (buildings, the ground, trees, etc.) and simulate their local impact on sunlight, wind, temperature and air humidity. The basic element of modelling is often the 'urban canyon', bounded by the street and the buildings that border it.

In city-scale models, the different individual elements of the urban environment can no longer be explicitly represented. These models therefore use the following features of the urban environment that influence wind, temperature and air humidity: urban morphology, the presence of impermeable surfaces, the relative share of built and natural surfaces, the physical properties of surfaces (albedo, emissivity), and materials (thermal conductivity and capacity). The influence of vegetation, heat storage and radiative trapping in streets can be incorporated into the models in a wide variety of ways.

The major results

Numerous studies confirm that urbanization modifies surface energy flows and is thus linked to an increase in air temperature and a decrease in its humidity, whatever the climatic context. This creates the phenomenon of the UHI, in contrast with the lower air temperatures of less urbanised areas. The spatial pattern of the UHI effect is linked to the morphology of the city, and its magnitude and footprint vary according to the season. Thus in temperate environments, the zone exceeding the magnitude of 2°C (the threshold above which urbanization is considered to have a signature) is much larger in colder seasons than in warmer seasons. In contrast, the maximum intensity of the UHI effect appears to be less season-dependent.

Studies agree that the greenest neighbourhoods have lower surface temperatures than more built-up neighbourhoods. In Marseille, eight types of urban districts were identified, with each characterized by an average temperature and a standard deviation reflecting the heterogeneity and combination of the characteristic surfaces of the district. A study conducted at a finer scale in Tel Aviv distinguished between the thermal behaviour of the different urban features. During the day, the elements that contribute most to heating the air are roofs, streets and paved ground exposed to the sun, with asphalt-covered streets and roofs reaching the highest temperatures. At night, exterior walls and trees have the highest temperatures, while open spaces, which are exposed to direct sunlight during the day and to exchange with the sky at night, have the greatest daily temperature differences. The contribution to the UHI increases for the following ground surfaces in order: grass, bare soil, paving, concrete, and asphalt.

To study the impact of urbanization on a city's air temperature, it is necessary to differentiate between the temperature increase linked to urbanization and that due to global warming. It is thus possible to compare the observed or simulated temperature difference with that globally identified in relation to climate change, or to create models by combining climate change scenarios with or without urban development. On the other hand, urbanisation seems to have little impact on maximum temperatures.

Solutions to mitigate the impacts of urbanization

The solutions proposed in the literature are aimed at influencing the nature and properties of various surfaces: horizontal (floors, infrastructure and building surfaces), vertical (walls) and sloping (roofs). Roofs have a major influence on the energy consumption of buildings, and they are now seen as additional surfaces (can be used for installing solar panels, gardens, etc.).

Grey solutions (relating to building materials)

The search for increased surface albedo is very well studied. This is achieved by using light-coloured, smooth coatings for paving, roofs and walls. Reflective roofs thus maintain the surface temperature at a lower level (Table 3.2), and reduce the energy transmitted to the building as well as to the air in the urban canopy. Reflective walls help to improve summer comfort in buildings. However, they have the disadvantage of reflecting solar fluxes, which are not absorbed, to the surrounding surfaces (source of inconvenience).

As regards paved surfaces, light-coloured coatings are of interest compared to conventional surfaces that absorb solar energy. The other option being explored is the search for evaporative pavements, which heat less due to the consumption of a portion of the solar energy by water evaporation. One solution involves watering (impermeable) pavements during hot periods, while a second involves retaining rain and runoff water in a porous coating.

The impacts of these strategies, however, remain poorly-understood, and they require further testing. Surface coatings have also undergone technological innovation in recent years aimed at developing their multifunctionality. Photovoltaic ground coverings, for example, in addition to producing electricity that can be used for lighting, allow the surface temperature to be reduced compared to conventional pavements. Table 3.2 shows the different technical solutions available to mitigate the urban heat island, as well as their limitations.

Table 3.2. Key local-scale technical solutions for urban heat island mitigation

	Principle	Technical options	Surface temperature decrease	Decrease in air temperature in the area	Other functions	Disadvantages, limitations
Solar surfaces	Absorbs and value adds to solar radiation	Photovoltaic surface covering	Medium (5-10°C)	Low (<1°C)	Electricity generation (for lighting)	Still at the experimental stage
'Cooling' coatings on surfaces	Reduces absorption of solar radiation	White surfaces	Very high (>15°C)	Low (>1°C)		Glare
		Grey, green, blue	Medium (5-10°C)	Low (<1°C)		
Evaporative pavements	Evaporative cooling	With watering	Very high (>15°C)	High (>1°C)		Water consumption
		Porous asphalt retaining rainfall	Medium (5-10°C)	Low (<1°C)	Rainwater management	Little feedback (Japan)
Bare and vegetated ground	Evaporative cooling, evapotranspiration and shading		Very high (>15°C)	High (>1°C)	Recreation, forage, rainwater management	Maintenance
	Insulation, lower temperature rises due to evapotranspiration		High (10°C, <15°C)	Low (<1°C)	Rainwater management	
Vegetated (Green) roofs	Cools by evapotranspiration	Different types of plants	Depends on vegetation and substrate thickness	Low (effect limited to proximity to roof)	Interior cooling of the top floor	Maintenance
Reflective roofs (cool roofs)	Reduces absorption of solar radiation	Large numbers of different coatings	Very high (>15°C)	High (effect limited to proximity to roof)	Major interior cooling of the top floor	Winter energy consumption Maintenance (light)
Vegetated walls	Cools by evapotranspiration and/or shading			Some degrees in hot and dry climate	Acoustic advantages, interior comfort in summer	Water consumption for plant walls with substrate
Walls with strong albedo	Reduces absorption of solar radiation		Highly variable effects with conventional walls			Radiation, glare, winter energy consumption

At the scale of the urban fragment, only those solutions based on the use of materials with high solar reflectivity have been studied. Most of the results come from simulations; the others come from observations that have been made on small areas, and very few as part of the evaluation of a real-life project. These studies show the effect of day and night cooling generated by the increase in albedo of materials in the city; the intensity of cooling (approximately 1°C) strongly depends on the type of surface (ground, walls, roofs), the orientation and morphology of the streets, and the climate. In regions where sunshine is significant, the modification of the albedo of roofs is more attractive than their greening.

Green solutions (urban greening)

Green solutions have to date received the most research attention. Vegetation can involve the ground, roofs and facades. On bare or vegetated natural ground (lawn, trees), surface temperatures will be lower than on artificial ground, due to the insulating nature of natural materials, shading (for surfaces among trees) and evaporation/evapotranspiration promoted by water retention. The improvement in comfort in summer will be noticeable during the day under trees; on the other hand, grassed surfaces generate coolness at night but have little impact during the day.

Vegetated roofs have been proven to cool the interior and limit the rise of external temperatures near the roof. The thermal effect at ground level remains low; it varies according to the characteristics of the green roof (substrate, foliage density, etc.) and the building (height, insulation, etc.), and the type of climate. The impact of green roofs is greatest in hot and dry climates, less so in hot and humid areas, and lowest in temperate climates. However, green roofs can also improve other ecosystem functions, such as biodiversity and air quality.

When vegetated walls are sunlit, they absorb solar energy (and transmit little) and rise in temperature only slightly, thus improving comfort during the day. Effects on street air temperature depend on climate, the containment effect (shape of the street) and water. Vegetated walls keep the air cooler in streets where the confinement effect is significant.

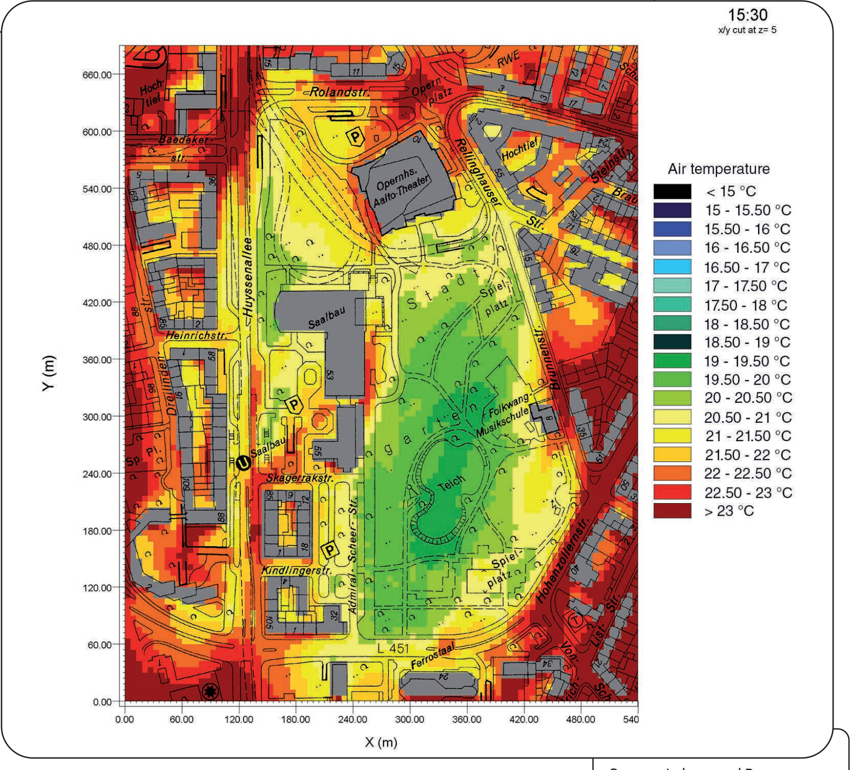
In conclusion, heavily vegetated sites remain cooler than heavily built-up areas. Green spaces create more comfortable zones locally during the day and at night, and they can also contribute to the cooling of nearby neighbourhoods (Fig. 3.3), depending on the prevailing winds and the morphology of the neighbourhood (whether streets more or less open to the green space).

Blue solutions (water based)

Depending on their size, standing bodies of water can have a positive or negative impact on the UHI. While the overall effect is positive for large water surfaces, some small surfaces store heat and become warm enough to warm the air at night.

Rivers appear to cool the air throughout the day. Some studies conclude that there is almost no effect, while others conclude that there is a significant effect, so it is very likely

Figure 3.3. Air temperature (°C) in and around an urban park in Essen (Germany). Map obtained with the ENVI-met model.



Source: Lahme and Bruse, 2003.

that the relationship between the effect of watercourses and urban morphology, which has been little investigated, is a major determinant of the climatic effect of watercourses on the surrounding neighbourhoods, as is riverbank development.

Also noteworthy is the development of roof basins (blue roofs) that store rainwater to relieve water network congestion. Their effect on the UHI has been little studied, but we can it is likely to be similar to that of sprinkler systems, and lower than that of green roofs which develop a higher evaporation surface.

Solutions based on urban design

In arid climatic zones, tall buildings and streets with a predominantly north-south orientation minimize the number of hours of thermal discomfort; and structuring the city in blocks made up of interior courtyards is preferable to structures of the 'canyon street' or 'large complex' types. However, these conclusions have been reached in particular urban contexts, and cannot be generalized because the importance of the urban form is not independent of other characteristics, such as the materials used and the types of ground coverings. For example, wooded vegetation could help improve comfort in a street open to the sky (creation of shade) but reduce comfort in a street with little openness (reduction in wind speed). A more holistic approach to urban development is required.

Current Gaps and Opportunities

Improving models for the evaluation of UHI reduction techniques

The objective of evaluating alternative urban planning techniques to reduce the UHI effect often requires a greater understanding of the relevant phenomena to be incorporated into the models. Models have already evolved considerably to adapt to new urban planning assumptions, but areas of improvement remain.

With regard to ground surfaces, a recent international comparison of 33 models showed that the inclusion of vegetation and natural surfaces, present even in small percentages, improves the overall result of the model, but also that the associated latent heat fluxes are the least well modelled components of the balance. This may be due to a lack of knowledge of soil moisture content, as well as the use of vegetation models designed for rural areas. While the greening of surfaces and new rainwater management practices are being considered in order to regulate urban climate, coordinated work with urban hydrologists is needed to better represent the interactions between vegetation, surface, soil and subsoil in climate models.

As regards climate-building interactions, research is beginning to explore the impact of the use of air-conditioning systems and building materials (passive or active). However, the great diversity of situations makes analysis difficult. Exploring a wider range of solutions requires taking into account the interaction between buildings and the urban climate, and therefore developing tools to represent both the physics of the building and the microclimate.

Concerning the urban layout (orientation, density, heights etc.), existing studies show the importance of research on this determinant, but also that each site requires specific analysis due to unique conditions (regional climatic conditions, topography, presence of watercourses, size/density/nature of vegetated areas etc.).

Modelling at a city scale

Very little research has focused on the diagnostic methods required in developing urban strategies to better cool the city. The difficulty is that there is no universal solution, and the effects of solutions depend very much on the particular urban configuration. Similarly, urban planning policies are not assessed in terms of climate impact. To do this, it would be necessary to formally model specific policies (which requires defining the changes in urban morphology at a plot scale) and then evaluate them over a large area using tools that are not yet able to describe urban morphology in detail. Thus, solar trapping and ventilation at a city scale are poorly treated in relation to the urban layout, materials and nature of ground surfaces.

Land Take and air pollution

To our knowledge, there is no scientific work focusing on the effects of land take (or urbanisation) on air pollution, nor any studies on soil pollution caused by air pollution. Many studies analyse pollutant emissions and concentrations and their trends in cities, or show the impact of the development of large urban agglomerations on pollution, based on observation or modelling. A few studies have compared different urban forms, however these studies consider only a few pollutants and certain pollution mechanisms, and develop analyses on a region, a pollution event, etc., and it is difficult to draw broad conclusions.

The origin and variability of air pollution

Air pollution processes

The processes governing air pollution are multiple and complex. They involve local biogenic and anthropogenic emissions of hundreds of particulate or gaseous pollutant compounds, along with pollutant inputs from neighbouring or distant areas. They involve physicochemical interactions between these compounds and the creation of secondary compounds, as well as thermal, meteorological and climatic processes that disperse, transport and transform these pollutants, and they involve resorption through dry or wet deposition etc. Thus land take (change in land use and urbanisation) cannot be linked to its effects on air quality in a simple manner.

The effects of air pollution are numerous: they affect, directly or indirectly, human and animal populations, flora, natural environments, the living environment, and buildings etc. There is, as yet, no synthesis of the impacts of air pollution. In addition to the direct effects of air pollution, there are indirect and long-term impacts through the transfer of pollutants to water, soil and the food chain. Effects on human health are multiple, difficult to characterize (because they result from exposure to relatively low but long-term concentrations of pollutants), and difficult to separate because these pollutants are mixed with ambient air pollution (which also includes indoor pollution from buildings). The effects on fauna, flora, buildings and cultural heritage are poorly documented in the literature, probably because they are considered to be of lesser importance in relation to health effects on populations.

Spatial variability and air pollution parameters

Air pollution particularly affects large urban agglomerations, with serious implications due to high emissions (traffic, heating), temperature inversion phenomena that can prevent the dispersion of pollutants, heat islands that not only exacerbate the pollution but probably its effects, and the large number of people exposed. However, pollution varies depending on the geographical (topography, altitude, climate) and meteorological (wind speeds and directions, precipitation, temperatures) contexts, the nature of emission sources (industry, traffic, heating, etc.) and natural sources (forests, deserts, oceans). Locally, concentrations vary greatly with distance to the sources, the building level, and street or building configurations.

Air pollution trends

In France, anthropogenic pollutant emissions are decreasing due to the implementation of regulations and pollution control technologies (catalysts, particulate filters, etc.). These reductions, however, mainly concern regulated pollutants, while other pollutants (uncontrolled or linked to new technologies or fuels) may persist or emerge. Pollutant concentrations are also falling, but less rapidly (-20% in 15 years for nitrogen dioxide and the smaller PM10 particles), while ozone pollution is increasing.

This encouraging trend is not occurring everywhere in the world, and regions that are experiencing strong development are seeing their pollutant emissions increase considerably. Thus, on a global scale, anthropogenic emissions of NOX and PM10 are still growing at a rate of 1 to 3% per year.

Urbanization and air quality/pollution

Several studies have attempted to understand the impact of urbanization on air quality through ground and/or satellite observations of pollution and land use, or by simulating the emission and movement of pollutants, with the most comprehensive simulating the entire process, from land use to pollutant concentrations and human exposure. The simulations cover different urban development scenarios or the relocation of populations and activities; the simulations concern episodic pollution (a few days) or an entire year, and concern a given agglomeration or region (on the basis of local data availability). This research, enhanced by studies on urban greening and the influence of urbanization on meteorology, provide insights into the consequences of urbanization.

Urban development and worsening air pollution

Pollution increases with urbanisation through a relative growth of activity linked to the population, through an increase in mobility, and consequently through an increase in anthropogenic emissions and concentrations of certain pollutants in and around urbanised areas. Finally, urbanization increases the number of people exposed to these concentrations, which leads to an expectation of negative impacts on the health of populations. These effects could diminish with the advent of cleaner technologies, emission control regulations and monitoring of concentrations, although this may be offset by the emergence of new pollutants, changes in uses or increased population sensitivity.

Relative influence of land use in relation to anthropogenic emissions and exposure

The most important aspects around increased pollution are the increase in anthropogenic emissions, the level of background pollution concentrations, the number of people exposed, urban sprawl and increased mobility. Less important parameters include changes in land use, possible reductions in natural emissions (negligible compared to anthropogenic emissions), and changes in local meteorological conditions linked to urbanisation. The same applies to the configuration of neighbourhoods, streets and buildings.

Effects of urban sprawl and densification on emissions and exposure

Urban sprawl results in an increase in air pollution at least as great as that which would be linked to urban densification without sprawl, and greater if we consider that it significantly increases the distances travelled and the dependence on cars.

The densification of an urban centre optimizes the city and its accessibility, but increases people's exposure to high levels of pollution. Low density extension (of the current peri-urban type, or urban sprawl) generally worsens the effects (increase in concentrations of PM_{10} and ozone) with, however, areas of lower pollution and the dilution of certain impacts (PM_{10}) over larger areas. A higher density extension or a multipolar or more homogeneous organisation of the city could make it possible to optimise the organisation of travel, contain the increase in anthropogenic emissions and limit the populations exposed to the highest concentrations. Urban greening contributes overall to reducing air pollution, even if this effect remains rather weak. Urban design and neighbourhood configuration can also contribute to reducing air pollution, although the potential is also rather limited.

State of scientific knowledge, research needs, and policy tools

The discussion of the influence of land take on air pollution, along with the review of the literature, have shown that many important issues are little studied. We note the following: there is a lack of scientific literature on certain aspects of air pollution, there are a lack of quantifiable factors or estimates that would make it possible to examine the predominant effects, and much of the work is limited in scope (few pollutants and few mechanisms). Generally speaking, more synthesis is needed to develop a more comprehensive understanding of air pollution (from land use to concentrations, exposure and effects on populations), and to take advantage of the many studies aimed at analysing the links between urbanisation, its forms and air pollution.

Simulations should also be developed based on French case studies (agglomerations with pollution issues, typical contexts) in order to broaden the analyses and document the effects under different scenarios. This would involve, in particular, identifying and combining the most appropriate tools to enable analysis ranging from the impacts of urban development to the impacts of air pollution, including the analysis of human exposure and extrapolation to health impacts.

The analysed literature has few suggestions in terms of policy tools. However, the conclusions of this analyses allow us to identify the following strategies that could reduce air pollution or its impacts:

• improved spatial organisation of the city that minimises mobility needs, distances and anthropogenic emissions without, however, leading to high densities of people exposed to high levels of pollution (less concentrated, less spread out, more homogeneous or polycentric city);
• favourable configurations of buildings, neighbourhoods, streets, etc. that promote airflow and reduce pollution, and optimize people's exposure, depending on their activities, to the lowest possible levels of pollution;
• the greening of cities;
• the development of eco-neighbourhoods and modes of transport that are eco-friendly, active and public, which would contribute to the creation of less-polluted areas.

Even if it is possible to envisage the lowering of pollutant concentrations in cities, it is difficult to assess the reversibility of impacts (for future generations). It is also difficult to distinguish the marginal effect from the overall effect of artificialization on air pollution.

Conclusions

Through this discussion of the physical urban environment, we have examined the relationship between soil artificialization, the urban heat island (UHI) and air pollution, all of which affect thermal and acoustic comfort and air quality. The analysis is based on a 3D vision of the city that integrates its vertical dimension. The developed surface of the city (building surface + impermeable surfaces) at different scales (individual building, neighbourhood, city) and vegetation are the study foci for energy (radiative, thermal) and water transfers between the atmosphere, the ground and the interiors of buildings. The airflow processes are superimposed on the exchange of energy and water in order to achieve an integrated description of water, energy and material flows.

This review of the best available knowledge reveals the influence of the various urban morphological characteristics such as the nature of surfaces (materials, substrates) and surface properties (permeability, thermal characteristics, and optical characteristics) on the various processes. Moreover, any increase in urbanization (expansion and/or densification) will, through increased activities, contribute to increases in heat, noise and pollutant emissions. In the context of global warming, several studies have shown that urbanization can accentuate the phenomenon of rising air temperatures at the local level. However, few studies have been conducted on the joint effects of climate change and urbanization on other parameters such as air humidity and wind. Some solutions proposed to combat UHI are more technological in nature, and are generally based on the reflective properties of surfaces (grey solutions based on the development of mono- or multifunctional surface coatings). Others aim to approach natural energy and water balances by relying on water systems and vegetation (green solutions, blue solutions such as rivers and basins) the positive effects of which depend on the size of the water body and the urban design. Finally, some solutions utilizing urban design and planning may have an impact on heat as well as air pollution. The interactions between the various tools are complex, however, and without a broad view of the entire system that encompasses the various parameters involved, actions can lead to an opposite effect to that initially intended. Vegetative solutions, for example, are increasingly being studied and mandated, but the related issue of water availability is rarely addressed simultaneously. Similarly, solutions must always be examined with regard to health (pollution, allergies), climate change mitigation (CO_2 emissions) and economic aspects (no-regrets solutions). Research advances point towards the most thorough integration possible, for example by linking micrometeorological and acoustic models, and by developing urban planning policies that take into account the UHI phenomenon. Data acquisition at local and broader scales remains a challenge to improving mapping (temperature, noise, and air pollution) as does the validation of models.

4. Agricultural land, agricultural activities, and land take

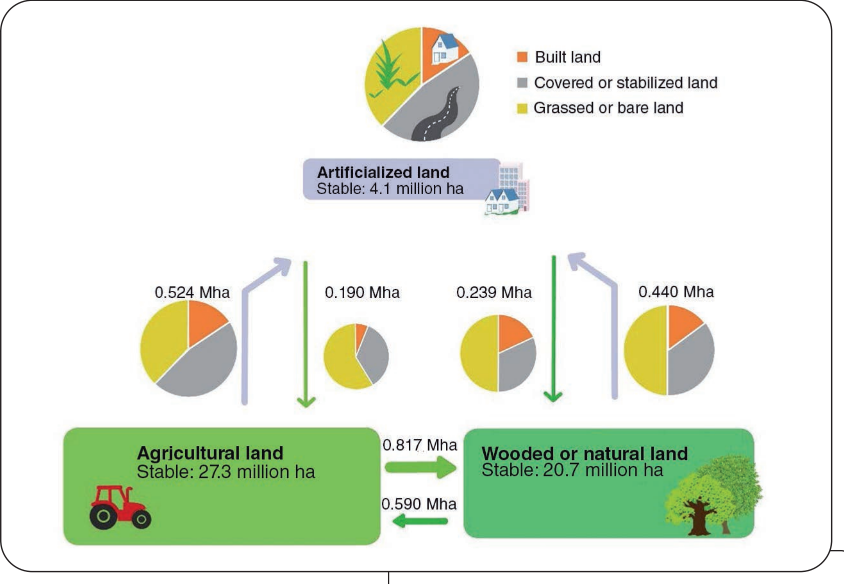
Land take is equally the subject of attention for its environmental impacts, which as we know depend to a large extent on the way in which it is practised, and for its impacts on agricultural activity. This impact on the quantity of agricultural land, agricultural production and the conditions under which agricultural activity is carried out is often difficult to assess. It is even more so as the determinants of land take and/or reduction of agricultural land, which can be examined through the income from agricultural land, are multiple. A fundamental issue involves how this agricultural area is defined in a context where boundaries differentiating territories are increasingly blurred. In rural or peri-urban areas, land take happens in agricultural, forest or semi-natural areas, the competing interest of which is their economic value – whether directly for the owner (who expresses it through his/her decisions as they relate to the land), or indirectly for the community. This public benefit from the land is preserved by the regulation of uses that can compensate for market failures, particularly with regard to the landscape, recreational areas, ecosystem services and natural risk management.

Direct impacts of land take on agricultural production

Losses of agricultural land from land take

Recent assessments of land use change in France have documented the loss of agricultural land, to which the shift from agricultural land to artificial land has contributed significantly. In addition to the net balances on which most analyses are based, a more detailed examination of exchanges between the various categories of land use, and the consideration of exchanges between agricultural land and natural and forest land, leads to somewhat more nuanced conclusions. The flow chart for 2006-2014 from the Teruti-Lucas data (Fig. 4.1) shows the extent of agricultural land losses to wooded and natural land (-287,000 ha and -530,000 ha, respectively), which far exceed agricultural losses due to land take (-524,000 ha). Of course, these changes are more easily compensated by reverse flows from forest and natural land (+273,000 ha and +317,000 ha respectively) than from artificialized land (+176,000 ha), the reversibility of uses being much easier between agricultural and wooded or natural land than between agricultural and artificialized land. Thus, the continued loss of agricultural land in France combines both a process of agricultural abandonment and recultivation, mostly on the fringes of these productive areas, and a process of soil artificialization that is more difficult to reverse.

Figure 4.1. Land use change by use from 2006 to 2014.



Source: Teruti-Lucas, 2014, SSP, MAA (graphics: Elodie Carl).

From the perspective of artificialized land, slightly more land take comes at the expense of agricultural land than from the sum of wooded (227,000 ha) and natural land (213,000 ha), and the fact that two thirds of land take was at the expense of agricultural land is explained by the proportionately smaller return of artificial land to agricultural land (190,000 ha) than to wooded or natural land (124,000 and 115,000 ha). Finally, it should be noted that, of the 964,000 ha of land that changed use towards artificialization during the period 2006-2014, half remained grassed or bare, while only 15% was built on. Conversely, 65% of artificial soils that were returned to agricultural, forest or natural uses were already grassy or bare, with very little built land returned (less than 5%). The large share of newly-artificialized land that was not sealed or stabilised during the period should lead to a more nuanced assessment of the negative environmental impacts of the land take.

It is clear that overall loss of agricultural land is significant, but in order to understand the full dynamics of this loss, it is necessary to consider the processes that lead to the artificialization of this land as much as processes that are responsible for agricultural abandonment and, conversely, for (re)opening up wooded or natural (or perhaps fallow) land to agricultural production. These last two processes, on the margins of the scope of this exercise, naturally affect areas with different agricultural and landscape characteristics from those affected by the first.

Land take is not distributed uniformly. At the French scale, land-use change towards artificialized land is a phenomenon which is concentrated in the immediate vicinity of cities and which spreads within peri-urban areas. In doing so, and because cities have historically often been founded where it was possible to feed them without excessive transport costs, this phenomenon is likely to have a particular impact on some high-quality agricultural areas. These areas may already lack local agriculture, natural recreational and/or heritage areas for urban residents, or natural coastal and/or tourist areas that are important from a biodiversity perspective. The issue is therefore not limited to the quantity of land but also to the quality, productivity and ecosystem services from which society previously benefited. Chery et al (2014) showed, on the basis of soil classification in France at 1:1M scale (while stressing the limitations linked to data accuracy), that land take preferentially affected land with high agricultural potential (representing approximately 45% of the territory's surface area). They also show that some rare soil types characteristic of wetlands are also strongly affected by land take, while soils characteristic of forest environments are the least affected.

Agricultural land thus appears to be easily convertible, and their conversion to artificialized land is difficult to reverse. The status of agricultural land is at the heart of the issues involved in its preservation, since it is particularly sensitive to urban sprawl and illustrates the tensions surrounding the public regulation of land use.

From land losses to biomass loss estimates

To estimate the impact of land take on agricultural productive capacity or on production losses measured in biomass, it is necessary to know the quality of agricultural soils prior to their artificialization. However, there is no consensus within the scientific community on the concept of the agronomic quality of agricultural soils, which has led soil scientists to favour the identification of a set of biophysical soil characteristics rather than the construction of a composite quality indicator (agronomic and/or environmental). This is one of the reasons why studies to assess production capacity losses related to land take are rare and have important limitations. However, some empirical work has attempted to produce maps of soil quality indices and compare them with the phenomenon of land take in terms of loss of productive capacity. While the relevance of this question is undeniable, this research is based on many assumptions and approximations, and its results should be viewed with caution.

Thus, the best estimates of potential production are based on crop models, which, unless the number of simulations is increased, are unreliable on the scales of very large territories (national or international) due to strong local variations in soil and climate conditions and a strong heterogeneity of agricultural production types and cultivation practices. These estimates are, moreover, limited to major crops for which sufficiently reliable crop models exist. However, the quality of the estimates of these modelling approaches is constantly evolving.

By combining a *Cropland Productivity Index*, derived from data from the *SoilProd* model (Tóth *et al.*, 2011), with land use changes recorded via CORINE Land Cover (CLC), Tóth (2012) and Aksoy *et al.* (2017) showed that in France, 70% of urbanisation takes place at the expense of very good quality farmland, bearing in mind that, according to the classification used, this category of land itself accounts for 68% of France's land. Thus, given the imprecision of these estimates, the differential to the disadvantage of these favourable farmlands is not significant, and land take affects soils of different qualities equally. Their estimates of losses in productive capacity between 2000 and 2006 would be equivalent to a loss of 0.26% of total agricultural production in France, which would be in line with the European average of 0.26%, and a per capita loss also in line with the European average. A similar but finer-scale study for the Languedoc-Roussillon region used a quality index essentially based on the Useful Soil Water Reserve. It estimated that land take disproportionally affects soils with the highest agronomic potential, but without going as far as quantifying the loss of productive capacity. Moreover, these estimated losses of production capacity, which are quite low overall, appear to be relatively insignificant in relation to all the other factors of variation and uncertainty affecting agricultural activity and production levels, given the possible combinations of production and the way in which agriculture and markets can adapt to this type of development.

Crop intensification on remaining arable land can compensate for the observed losses (Bren d'Amour *et al.*, 2017). To properly consider this mechanism, approaches should combine previous results with economic models integrating market reactions and the trade-offs that producers must make between different production regimes. In France, over the last 30 years during which the artificialization of agricultural land has been sustained, studies taking this aspect into account have not found a significant drop in production volumes attributable to urbanization, and no scientific study presents any statistical evidence to this effect: the losses in productive capacity referred to above are obviously potential losses and must be analysed in terms of loss of options in a non-renewable resource context, which this literature does not do.

Ultimately, debate continues between, on the one hand, those who consider that land take has a significant impact on agricultural productive capacity and that the accumulation of land losses in the long term can jeopardize this activity and, on the other hand, those who consider that this impact, considered at a broader scale, is often exaggerated, especially in Western Europe, and that we are still some way from a shortage of agricultural land. The impacts of land take in terms of irreversible losses of arable land cannot be assessed without comparing them with the overall stock of arable land, whether used or not, particularly in a context of agricultural decline in rural areas where abandonment is reversible.

Nevertheless, the impacts of land take on agriculture are felt very harshly at the local level, particularly in peri-urban areas where farmers are directly confronted with this pressure. This strongly disrupts agricultural activity as well as the local organisation of production, due in particular to the fragmentation of agricultural land caused by the wave of land take, an effect which will be address in more detail later.

From an economic perspective, land quality is defined for a given use and corresponds to what benefits (private or social) belong to the owner (private quality) or society (social quality) once all of other factors of production have been met, which makes the assessment of the quality particularly complex. The foundations of agricultural land conservation policies based on soil quality indices are the subject of numerous reservations in the United States and France (criticism and abandonment of the use of the 'Agricultural Land Map' prescribed in the Agricultural Orientation Act of 1980).

Income from agricultural land, a driver of land use changes

Any analysis of the mechanisms by which agricultural land can undergo a change of use to become artificialized must occur through the lens of the income differential between competing uses. Dynamic urban development models focus on the factors that explain a landowner's decision to convert a parcel initially in agricultural, forest or natural state to built-up land. The price of undeveloped land in peri-urban or rural areas is related to at least three components: the value as agricultural or forest land, the cost of conversion, and he expected future income.

Given accurate and complete information, landowners will choose the optimal time to convert their parcel in order to maximize their expected net profit. Disregarding option values, the decision to build takes place when the expected income from urban use is higher than the agricultural income plus the conversion costs.

While keeping in mind the very strong difference in value per unit area between built land and agricultural land (55 times higher for built land; 1.72 €/m² against 95.5 €/m², Box 4.1), it is necessary to reflect on the way in which agricultural land incomes develop and the elements that comprise them, in order to see how they change in line with the advance of the urbanisation front or the densification of the peri-urban area. The value of land remains a determining factor in the decisions of private stakeholders to convert their agricultural land into buildable land, although it is not the only factor considered. Policy tools can therefore influence the decisions of public and private stakeholders. The agricultural income depends on two main categories of factors: internal agricultural factors, and external factors.

Box 4.1. The impermanence syndrome

Proximity to the city can have negative effects on agriculture by shortening the time horizon on which farmers' decisions are based. This impermanence syndrome implies that farmers under-invest in their activity, which helps to diminish its potential value. Since the change in use is rarely reversible and that its prospect is associated with an increase in the value of land, the conditions for the emergence of an option value are present. The option value is added to the value of the agricultural activity, and comes from the ability to wait for new information relevant to the urban value of the land before choosing to convert or sell.

Internal agricultural factors

The quality of agricultural land, although difficult to estimate, is taken into account in the calculation of land value. This quality constitutes a barrier against the artificialization of agricultural land and must be maintained, although its weight varies greatly between and within regions. The use, the type of agriculture practised, etc. make the practice more or less dependent on the biophysical attributes of the land (altitude, slope, soil quality).

The climate is also the subject of particular attention. In France, research is incorporating the influence of climate on the price of agricultural land and land use choices in terms of future development scenarios up to 2050. Taking into account urban expansion (+1 million ha), it appears that annual crops and forests would increase (+1 and +1.5 million ha respectively) to the detriment of grasslands and perennial crops (-2.5 and -0.3 million ha respectively). The effects of climate are not limited to annual crops or grasslands, however, and also affect the decisions of livestock farmers and on the choices of other perennial crops.

In contrast, the need for agricultural inputs is generally not reflected in the price of land. However, the availability of water (underground or irrigated) increases the expected income from agricultural land and therefore its value. The same is true for investments made to 'improve' the usability of the land, such as enlarged field sizes, bores, or drainage works. Finally, with a view to limiting agricultural decline, it is commonly accepted that support for agricultural stability (Common Agricultural Policy, Organic Farming, etc.), affects the value of land and sustains agricultural activities. Production quotas and permits also impact the price of agricultural land, whether it be chemical spraying rights, or limits in terms of nitrates. Conversely, amenity effects that increase the supply of ecological benefits can generate additional income from the land.

Factors external to agriculture

Among the external factors likely to affect land values, and thus the possibility of conversion of agricultural areas, the proximity of already urbanised areas or natural areas must be considered. Also, the roles of SAFER and local authorities should be examined.

Proximity to urban centres, as with road infrastructure, is both a threat and an opportunity for agricultural activities. It can generate new market outlets and lead to a specialisation in products with high added value. In this context, local school canteen supply programmes are a significant tool. On the other hand, towns or the coexistence of competing activities in the same area can be a source of land use conflicts and can hinder agricultural activity (fragmentation of agricultural areas by transport infrastructure, restrictions on certain agricultural practices, etc.). At the same time, the presence of non-agricultural populations can help maintain agricultural activity by providing access to services and jobs. However, this proximity can also intensify land pressure and increase the vulnerability of agricultural land if it does not benefit from special protection (see Chapter 7).

Natural areas in the vicinity of agricultural land can lead to both positive and negative spillover effects, but generally of lesser magnitude than the above factors. Marginal agricultural land will be more vulnerable to abandonment and natural encroachment by vegetation, but a parcel of agricultural land can benefit from the attributes of neighbouring natural parcels through externalities such as open spaces or ecosystem services. Scenery and natural habitats positively influence farmland values, as do ecosystem services provided by natural areas (lakes, rivers, forests and conservation areas). The development of tourism and recreation, made possible by natural and forest areas, also adds value to agriculture, which can preserve land from changing use. In France, environmental protection mechanisms can locally reduce land availability, but there is no direct effect on agricultural activity.

Land pressure in coastal areas. As land is physically scarce along the coasts, its value increases in proportion to demand. Thus, in France, the price of buildable land for sale in non-urban areas is 60% higher on the coast than the mainland average. The parcels of land are also smaller (-25%), reflecting the effect of the price on the property, but also the legacy of the market garden landholdings typical of coastal areas. Although agricultural land consumption is not specific to the coast, it is particularly high: in France, farms in coastal municipalities lost 25% of their useful agricultural area (UAA) between 1970 and 2010, compared with 12% in the hinterland and 10% on average in metropolitan France.

Reclamation of coastal wetlands was first developed on the shores of the North Sea, before spreading worldwide. Initially practised for the benefit of agriculture, aquaculture and salt production, from the 19th century onwards it was mainly carried out for urbanisation and economic development, for which it provided cheap land and avoided conflicts over encroachment into agricultural land. Large cities such as Amsterdam, Venice and Tokyo have expanded over former marine wetlands. The installation of port infrastructure and large industrial plants has also been an important factor in land reclamation. In the Seine estuary, between 1834 and 1978, intertidal areas fell from 130 to 31 km^2. Worldwide, 67% of marine wetlands areas have been reclaimed in this manner during the historical period.

The institutional context significantly changes the value of the agricultural asset. The securing of property and use rights, as well as the parcel layout, plays a role in land prices and agricultural value. Transaction costs are also included in the price of land, which leads to greater rigidity in the land market, whereby otherwise mutually beneficial transactions may not be realized (Box 4.2).

Box 4.2. The value of land in France in 2015

According to INSEE, cultivated land was worth 481.5 billion euros in 2015, while the value of land supporting buildings was almost 10 times higher (4,782.5 billion euros). However, there is strong variation within each of these two sectors, as shown by the asset accounts from a macroeconomic perspective. The price of freehold agricultural land in the Haut-Jura was 0.14 €/m^2, compared to 140 €/m^2 for a *Premier Cru Appellation d'Origine Contrôlée* vineyard in Burgundy (New land price series, SSP-SAFER). Moreover, urban land is not directly comparable across built areas. The price of a plot of land to build a detached house varies from 19 €/m^2 in Limousin to 200 €/m^2 in Île-de-France (Survey on the price of building land, SOeS).

Local factors influencing the likelihood of agricultural land being converted to artificialized land

In a peri-urban context, the reasons for the abandonment of agricultural land or its 'under-utilization' are profoundly modified as a result of land pressure and the fragmentation of agricultural territories caused by the integration of artificial surfaces. As discussed above, abandoning the agricultural use of land is the spatial expression of a process of marginalization in which the agricultural exploitation of land ceases to be profitable in comparison with the income that land use conversion can bring.

As also mentioned above, land pressure implies, in densely populated areas, that the opportunity cost of denser land occupation is unfavourable to continuing agricultural use. A very detailed study of southern Spain shows that the agricultural parcels closest to urbanised areas (0 to 1.2 km) and roads (less than 2.5 km) are the most likely to be sold for urban use. However, because of a trend towards intensification of agricultural activity within these particular areas (accompanied by a change in the type of production and the relative maintenance of agricultural uses), the areas most prone to land take are not always located in the immediate vicinity of these areas. The mid-zone areas, between 1.2 and 5 km from the centre of urbanised areas, are the most sensitive to conversion of use. The same type of mechanism can be found in Canadian examples, in the wine-growing plains of southern France, etc. The process does not appear linear, however, and the very extension of land take in these peri-urban areas may be hampered above a certain threshold by the reactive dynamics of local agriculture (Box 4.3).

Box 4.3. Non-linear processes in a peri-urban context: the neighbourhood effect

When land take begins, the fragmentation of farms is very significant as it amplifies the ongoing process. This phenomenon is called the 'neighbourhood effect', i.e. it encourages farms neighbouring those that have abandoned parcels to artificialization, to do so in turn. However, after a certain amount of artificialization and fragmentation of agricultural holdings, a process of concentration and reduction in the number of holdings begins, which greatly slows down or even stops the process of land take.

Although few studies have examined the topic, they show that the fragmentation of agricultural areas and farms is having significant effects in amplifying the process of land take that has begun. In addition to the increased consumption of local agricultural land, the increasingly complex interweaving of urban and agricultural functional spaces is central to the permanent reconfiguration of agricultural plots, which obliges local farmers to constantly adapt to ever-changing and more restrictive conditions for carrying out their activities. These tensions are much greater than the simple share of the municipal surface area allocated to non-agricultural and non-forest uses might suggest: for example, in the peri-urban municipalities of Île-de-France where these tensions can be high, artificial surfaces cover only between 10% and 20% of the municipal territory. There nevertheless appears to be a spatial and/or temporal threshold where agricultural abandonment in favour of artificialization may slow down in peri-urban areas.

A similar dynamic can be found by analysing conflicts and disputes that develop in peri-urban areas. Conflicts over land use are of several kinds and affect all areas (noise or olfactory pollution, visual nuisance, health risks, nature or heritage conservation, etc.). Among these, conflicts between urban or peri-urban dwellers and farmers are frequent, without being predominant; they also vary more or less according to the stresses and nuisances generated by each of the parties involved. Beyond the direct and contentious conflicts linked to land use changes, through which agricultural land is considered as threatened by land take, there are also conflicts and disputes within which certain agricultural practices or facilities are seen as local nuisances. It is interesting to note that above a certain threshold, the spread of residential occupation of former agricultural land poses a problem insofar as households are eager to live close to nature (even if they have a fantasized image of it) and they prefer that the areas in which they settle retain some of the landscape characteristics that initially attracted them. Agriculture has a special place in this image of nature, which explains the possible mobilization of some recently-arrived residents against major infrastructure projects or additional residential development projects.

Not all farms located in peri-urban areas are equally sensitive to pressure to convert their agricultural land. Factors such as the financial position of the farmer and his or her debt levels, but also the adjustment costs or opportunity costs required for the change of activity (sale of movable and immovable assets, inadequate vocational training for an activity other than farming, etc.) have a major influence on farmers' decisions. The socio-economic characteristics of the farmer's family are also integrated into the farmer's decisions. Two factors increase the likelihood of a farm ceasing operation: the spouse working off-farm full time, and if both spouses were raised on farms. The type of farm, whether for animal production, field crops or market gardening, is also a determining factor in the cessation or maintenance of activity. In effect, the amount of value added per hectare, and thus the amount of agricultural income, varies according to the type of production. Irrecoverable costs are higher in livestock production, and regions dominated by farms specialising in livestock production are found to be less prone to cessation of activity than regions specialising in crop production (with equivalent regional socio-economic characteristics).

At the same time, many studies focus on the resilience of peri-urban farms as one of the factors that combat urban sprawl. They show a great diversity of strategies that can be grouped as multipurpose adaptations to the peri-urban context. It is thus difficult to determine whether high population densities reinforce or threaten agricultural activity: it can reduce the process of abandonment because of market opportunities, as well as accentuating it by providing work opportunities outside agriculture. Thus, the existence of secondary incomes for the farmer or his or her family can accelerate the process of abandonment, just as it can contribute to stabilizing agricultural activity. Above a certain threshold of non-farm income (and therefore of purchasing power), a positive effect on the recovery of farms can be seen, which is then based on the opening up of commercial opportunities linked to the changing eating habits of wealthy households. This situation also has the effect of making some small peri-urban farms less dependent on Common Agricultural Policy (CAP) production aid. Peri-urban farms have developed a wide range of adaptations to survive, but their common feature is the way they are integrated into the agri-food system, primarily based on their urban proximity. Some farmers are turning to small crops with very high added value (vineyards) or to niche markets. This results in an increase in the economic and social value of the multifunctionality of agriculture or, more often, into an increase in direct sales (Box 4.4).

Box 4.4. Integrating peri-urban farms into urban food projects

A new way of increasing farm incomes has emerged over the last couple of decades with the development or empowerment of local policies that integrate this agricultural issue into urban food strategies. Local food and agricultural policies re-examine the use of planning tools. The protection of peri-urban agriculture via planning instruments, freely deployed by municipalities, would be more effective than local urban planning, especially since they indicate local governance organised around an agri-urban agricultural development project, which then translates into a preparedness to protect agricultural land. This forms a strong tool for protecting peri-urban farms, provided that it integrates existing agriculture in the local area into its multifunctional dimension.

Conclusions and policy tools

While it is clear that land take can affect agricultural areas, this must be examined both quantitatively and qualitatively. In quantitative terms, there have been irreversible losses of agricultural land. While land take often plays a major role, these losses are also due to the more traditional phenomenon of agricultural decline linked to the cessation of agricultural activity. The latter results in significant flows of land-use changes between agricultural, forest and natural lands, affecting potentially less productive and more reversible land. Translating these flows into lost agricultural biomass production is difficult. At most, an attempt can be made to assess the loss of productive capacity due to the artificialization of agricultural land. Even if the losses of agricultural land through artificialization concern soils with good to very good productive capacity, the production losses that they could generate are, to a large extent, compensated by an increased intensification of production on other agricultural land. On a more qualitative level, some forms of land take, such as urban sprawl or the fragmentation of agricultural territories by housing or transport infrastructure, increase the areas of contact between agriculture and artificial areas, creating mutual inconvenience and nuisance between residents and farmers, and can disrupt the organisation of agricultural activities. With regard to these issues, the review of the scientific literature highlights research needs on the subject more than it allows conclusions to be drawn.

Having said that, with a view to limiting agricultural land losses in the medium and long term, in order to preserve France's agricultural production capacity and avoid hindering farmers' activities, policy instruments do exist.

In the first instance, decisions leading to the artificialization of agricultural land takes insufficient account of the quality of the soils targeted by conversion projects. Consequently, it is difficult to estimate the exact impact of land take on agriculture, both in terms of the loss of production, and in terms of the wider agricultural environment. An important, principal tool lies in enhancing our knowledge of agricultural soils in France at the parcel level. However, this mechanism is contingent on the agreement of a definition of soil quality.

Secondly, statistical analyses reveal the low reversibility of agricultural soils that have become impermeable. It is this category of land take that should be highlighted in land use monitoring to more accurately assess its impact on agriculture. Indeed, in the long term, and in an era of climate change, this reversibility is central insofar as studies show that localized agricultural uses will probably evolve due to the availability of water resources and climate change. If the conversion of agricultural land is approved, development projects should consider, and indeed favour, future reversibility.

Zoning policies appear to be a tool with great potential, but their implementation is not always effective in controlling the artificialization of agricultural land. This raises the question of the appropriate level of governance for agricultural land.

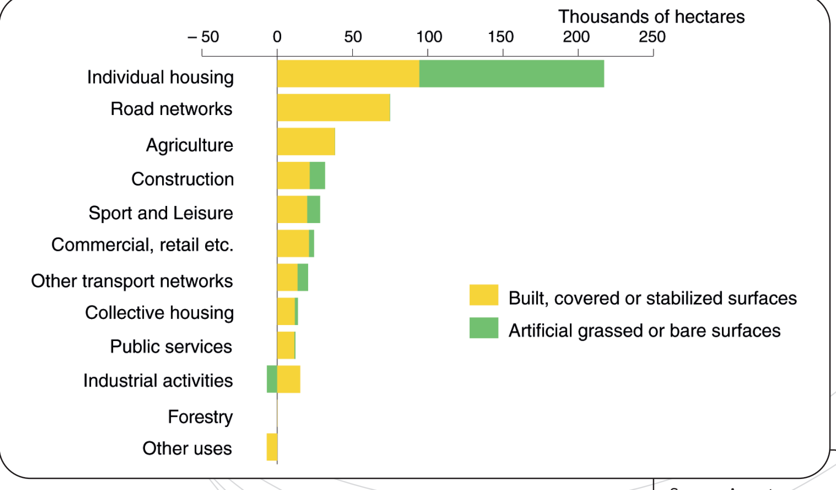
Finally, not all types of agriculture offer the same 'resistance' capacity to the phenomenon of land take. In a peri-urban context with strong land pressure, niche agriculture, but also agriculture integrated into a localised food system (SAT), is more sustainable than conventional agriculture. Participatory and local governance is therefore central.

5. Household location strategies and housing construction

Having analysed the environmental impacts and consequences of land take on the agricultural sector, we now identify the stakeholders and examine in detail the ways in which they are involved in this overall process. There are three main types of activities that take place on artificial soils: housing, intended directly for household consumption; economic activities, whether industrial or services (and to which administrations and public services are most often associated); and transport infrastructure, which link cities or serve urban or peri-urban areas.

In 2014, according to Teruti-Lucas, only 42% of the areas already artificialized are for housing, however this land use is most often the focus of attention because its rate of expansion appears to be the fastest. According to Teruti-Lucas, nearly half of the newly artificialized areas between 2006 and 2014 were for individual or collective housing (Fig. 5.1), with collective housing representing just 14,000 ha of the 242,000 ha of the extension

Figure 5.1. Amount of sealed or unsealed surface within newly-artificialized land uses 2006-2014 (thousands of ha).



Source: Agreste, 2015.

of artificial areas for housing. It should be noted, however, that while this trend is much larger than that for economic activities or transport infrastructure, its surfaces are generally less impervious than other types of artificialization since only 111,000 ha of the 242,000 ha subject to this trend are eventually built on, surfaced or stabilised, whereas 220,000 ha of the 243,000 ha intended for infrastructure or economic activities are sealed after artificialization. Thus, the extension of areas for housing results in a mix of surface coverings with varied environmental impacts.

In order to understand the processes underlying the expansion of residential areas, we must examine the mechanisms that determine the residential location of households and how they shape urban and non-urban landscapes. Beyond the urbanization process, these mechanisms are reflected in the current peri-urbanisation movement, which is primarily residential and spreads the artificialization of land beyond the city's borders. By exploiting these mechanisms, several public policy instruments can be considered in order to limit the extension of artificialization in both urban and peri-urban areas without jeopardizing access to housing and/or hindering the construction sector.

Housing preferences, urban sprawl and peri-urbanisation

Households' residential choices strongly drive urban sprawl and peri-urbanisation. However, in parallel with this pattern, the density of built areas within stable urban perimeters appears to be increasing, including in peri-urban areas. Therefore, there appears to be a dual phenomenon of expansion and intensification, which tends to be overlooked by studies that are too focused on sprawl, and which prompts some authors to speak of re-urbanization.

Trade-offs in the location of household dwellings

Basic models of the urban economy analyse the process of residential household location as a trade-off between housing costs and transportation costs incurred by households seeking to locate themselves around an employment centre. The former tend to increase with competition for land use, which becomes more acute near the city centre as densities increase, while the latter (whether monetary or expressed as the opportunity cost of time spent travelling) tend to reduce for those who are able to locate close to the same centre. It is through this simple model that we account for the spread of cities around their centre. The latter trend is particularly true since the weight of French household spending on accommodation is growing faster than that of spending on transport, and has been the case for several decades (Box 5.1).

This movement is accentuated by the conjunction of three complementary phenomena: population growth, with the population of metropolitan France projected by INSEE to rise to around 73.6 million in 2060, an increase of around nine million inhabitants (+14%); the

Box 5.1. Some characteristics of French households in terms of housing choice

In 2014, expenditure on housing accounted for 20.1% of the French household budget (compared with 18.5% ten years earlier), while the budget coefficient for transport fell from 10.6% to 9.8% between 2004 and 2014 (INSEE, National Accounts, 2010 base).

Children living away from parents, longer life expectancy, and changing family structures explain the decrease in household size and the increase in demand for housing. Small dwellings located in the city centre are difficult to access for those on lower incomes, thus fuelling the expansion of the urban area. In Berlin, for example, the ageing population and the increase in small households favour the development of buildings in peri-urban areas closer to the city, whilst reducing building in the dense city and in the more distant peri-urban areas.

In France, 58% of households live in detached houses. When asked about the type of residential environment in which they would like to live, 87% of French people preferred individual housing. Relocations are motivated by access to a garden (23%), an extra room (22%) or a pleasant view (19%). Green areas and landscapes, which are more associated with the peri-urban environment, are clearly popular.

decrease in household size which automatically leads to an increase in housing demand, and the preference expressed by households (especially French households) for individual housing (Box 5.1), which increases the demand for artificialized land both for buildings and for adjoining gardens.

In addition to these three components, there is the mixed role of the local attributes of natural versus urban amenities, and the associated benefits that households can derive from social interactions, most often bringing them closer to their peers. These two essential elements in the processes of construction and extension of housing areas will be discussed below.

In these circumstances, the relationship between population growth and the expansion of urban areas is not linear. In all industrialized countries, the latter is faster than the former and France is no exception. At the same time, when examining the changes in urban density (number of inhabitants per km^2) we find an increase, which indicates a more intensive consumption of urban space concurrent with urban sprawl. Angel (2011) projects, according to one scenario, a growth in urbanised space of 75 to 190% from 2000 to 2050 for Europe and Japan, a range consistent with the urban expansion experienced in France during the last half-century.

Thus, the dual trends of urban concentration and urban sprawl, characteristic of the so-called industrialized countries, is reflected in an expansion of city borders and a dispersion of housing (particularly individual housing) in peri-urban areas, which is particularly significant in France.

From urban sprawl to the emergence of peri-urban areas

The classical urban model consists of a more or less regular expansion of the city into the areas immediately surrounding it, with an arrangement in concentric circles characterized by a gradient of density of construction decreasing with the distance to the centre. However, we often observe non-continuous patterns of building construction in relation to urban space: this is the case of fragmented and disjointed peri-urban development, such as in France, which results in an urban sprawl of building constructions sprinkled in the middle of agricultural, forested or natural areas. Fragmented development can take place over the entire outskirts of the city, in the form of satellite clusters of parcels (fragments of urban area), dispersed ('diffuse' distribution of buildings in space) or in discrete strips of buildings. Unless strict, well-planned zoning is established, the transition zones between urbanised and rural areas will always assume specific forms of land-take that reflect the connection of centres and/or diffusion along axes.

The peri-urbanisation of housing in France

Peri-urbanisation is a major trend that began in the 1970s, and even several years earlier in Île-de-France. After slowing down in the 1990s, post-2000 data shows a recovery of the phenomenon, particularly around the largest urban centres. Peri-urbanisation has occurred through the spatial extension of the perimeter of influence of cities, i.e. by increasing the number of municipalities with large proportions of their working population commuting daily between their municipalities of residence (not included in the larger urban centre) and the latter. The development of these fragmented urban areas which are separated from the city results in urban sprawl, with alternating real estate constructions and agricultural, wooded or natural enclaves of varying sizes. It is in these areas that the problem of the extension of artificial surfaces to the detriment of agricultural land dominates. The role of the agricultural landowners and their income choices, as described in the previous chapter, are the main driving forces behind the potential for peri-urban expansion.

This fragmented development can take place over the entire periphery of the city or in a 'satellite' form, or in strips built separately from each other. This movement has historically taken place in two stages: first, by increasing the number of so-called peri-urban municipalities, before continuing with a process of densification within these municipalities, in contrast with the decline of central cities. The 1990s were marked by a demographic recovery in these cities and their suburbs.

Today, peri-urbanisation takes on more complex and varied forms. In particular, it is more often the result of the consolidation of formerly rural towns and villages or the increase in the size of peri-urban municipalities, which contributes to the evolution of metropolitan areas towards more multipolar structures.

A constantly evolving vision of the peri-urban environment

While not minimising the environmental and social problems posed by peri-urbanisation (in particular via peri-urban travel practices), a number of studies are now proposing more measured assessments. These aim firstly to move beyond the initial enthusiasm for a new dynamic of rural spaces offered by peri-urbanisation (by counter-urbanisation or suburbanisation depending on the terms used in debates at the end of the last century). Secondly, and conversely, they aim to avoid the image of inhabitants forced to move away from urban centres, relegated to soulless territories, and isolated in their homes and gardens. These approaches invite a rethinking of the methods to be implemented to place peri-urban territories in more sustainable trajectories.

With a quarter to a third of the European population living in peri-urban areas, new approaches to peri-urbanisation are proposed, but some may be controversial. Thus, some studies now find that residents make location choices based on lifestyle, and that places great importance on proximity to natural spaces and a shared feeling of 'living in the countryside'. The quality of life is popular among residents, who feel an attachment to these areas: relocation is rare. These are exactly the same reasons that drove the success of the first peri-urbanisation movements in the mid-1960s. Moreover, the peri-urban lifestyles have evolved and are no longer highly dependent on urban centres.

Social (re)composition of less dense areas

The image of a peri-urban 'club' in the minds of peri-urban residents is quite frequent, and by helping to drive the 'locking-out' trends in these areas (Box 5.2) contributes to the 'bad press' of these areas. This socio-spatial insularity is expressed in spaces dedicated to categories of population, the wealthiest living as close as possible to amenities and going so far as to express it in the form of a closure, as is the case for the majority of gated-communities, closed complexes or private neighbourhoods, which are developing in France.

Box 5.2. *Growth machine hypothesis* and *Homevoter hypothesis*: obstacles to peri-urban densification

According to the *Growth Machine Hypothesis*, developers and owners of undeveloped land exert political pressure for less restrictive urban development policies. Conversely, according to the *Homevoter Hypothesis*, owners have an interest in politically supporting, through the ballot box, municipal councils that implement restrictive urban development policies, because this increases the value of their assets. Since supply is then less elastic, it protects them against shocks that might otherwise affect the value of their assets.

Indeed, various tests of this hypothesis show that municipalities with a large proportion of homeowners tend to implement restrictive policies, not only in the United States but also in France. We can therefore distinguish two stages: a phase of strong population growth, driven by rural landowners' land ownership logic; and a stabilization phase associated with policies to preserve the living environment, which are supported by newly arrived peri-urban dwellers who wish to maintain their living environment and thus a low density of housing.

However, for the poorest households, this choice (peri-urban or rural) can have harmful consequences on their poverty, their immobility or their isolation in these territories where businesses and services are less accessible.

The regeneration or social reconfiguration of sparsely populated areas, often analysed as taking place to the detriment of the existing agriculture-based populations, is just as conducive to social diversification. Households within residential expansion tend to increasingly mix. While the agricultural population is decreasing, marking a change in agricultural practices and therefore landscapes, these areas are experiencing, at least in North America, demographic growth, sometimes with an agricultural professional integration.

Social inequality, urban configuration and land consumption

When households have the same preferences and differ only in income, the urban economy reveals that disadvantaged households are located in a central circle close to the employment centre, while wealthier households live in a ring around this circle. When the preferences of the two socio-economic groups differ, high- and low-income households are located in the centre or in the periphery according to the income elasticity of their demand for residential space and accessibility. In reality, the location of households according to their income is guided not only by distance from the centre but also by the presence of amenities (Box 5.3), which leads to two dominant types of urban configuration.

Box 5.3. Site attributes: the three main types of amenities

Natural amenities correspond to the topographical features of the space – for example a river, or a seaside. Historic amenities characterise the aesthetic and heritage aspect of the city – for example monuments, architecture or green spaces. Finally, modern amenities are characterised by the presence of public facilities, theatres, or the extent to which historical amenities have been renovated. These last two categories of amenities are positive externalities.

When space is homogeneous and isotropic, and households only differ by income, socio-spatial segregation is the normal product of the functioning of the land market: similar households make similar choices that lead them to co-location. By default (and therefore without redistribution), the land market generates socio-spatial segregation. When space is not homogeneous, due to the presence of natural, historical or modern amenities or the social neighbourhood, the outcome of the urban economy is less certain: urban configurations with rich households in the centre and poor households on the periphery (example: Paris) or the reverse (example: cities in the Western USA) are possible. Indeed, in European cities, historical and modern amenities are abundant in the city centres, which leads wealthy households to choose these central locations where land is expensive. Conversely, in the American city, which applies to most cities in the western United States, the heart of cities is poor in amenities while they are abundant on the outskirts. In this case, wealthy households choose these outlying locations where land values may be higher than those in the centre. History and geography (endowment of amenities) or sociology and political science (social quality of the area), more than economics, explain the prevailing patterns. However, each of these two trends will lead to a different type of urban land consumption on the periphery.

There is a two-way link between land consumption and social inequality: the suburban location of high-income households in a homogeneous and, even more so, heterogeneous space (amenities, supply of local public goods, social neighbourhood), is a source of socio-spatial inequality, and increases residential land consumption. Public policies that reduce either social inequality or the land consumption of wealthy households go in the same direction: if the public authorities pursue these two objectives, they result in win-win outcomes.

Descriptive statistical studies on this subject reveals the preferential location of wealthy households to be either in outlying suburbs or nearby peri-urban areas, thus contributing to the social inequality of areas (and to a significant consumption of agroforestry land). However, this unequal effect should not be exaggerated: it is within urban units that social contrasts are most marked, particularly if they are large, with peri-urban belts appearing less unequal. Peri-urbanisation has also contributed to these socio-spatial inequalities: migration of middle and wealthy socio-economic groups to these regions has contributed to social segregation in cities (Box 5.4).

Box 5.4. Social housing and the concentration of poverty

The large-scale construction of social housing in the post-war boom years has made it possible to house many families from the middle and lower socio-economic strata. However, over time, the poor quality of housing and its peripheral locations partly accounts for the current level of segregation of disadvantaged populations. Studies show that the poorest populations are relegated to the least attractive social housing. It is thus not social housing that is at issue, but the concentration of poverty.

The dynamics of the property market generate spatial segmentation, but the rules governing the operation of social housing, which make it available to a large proportion of the population without being able to force a household whose income has increased to leave a dwelling, have also contributed to a polarisation of the social housing stock.

Consequences of the peri-urbanisation of jobs on urban households

When jobs are decentralised around peri-urban areas or outlying suburbs (currently the case in France[12]), this movement may reinforce the trend of household relocation to outlying areas, as the main factor in people's choice of residential location remains access

12. Over nearly 40 years, the fastest growth in employment in France has occurred in the suburbs of large French cities, rather than in their most remote peripheries.

to jobs. However, if employees are forced to remain centrally located or in nearby suburbs, this can result in poor spatial matching of supply and demand in the labour market, mainly due to increased distances between home and work. Thus, if the households with the lowest incomes are in the city centres, they are disadvantaged when jobs are moved to the outskirts, and vice versa.

A restrictive urbanization and sprawl policy is therefore also conducive to better matching, although such restrictive land policies reduce market flexibility. However, this mechanism would probably not be general in scope: it would require fine-tuning on a local case-by-case basis. Moreover, at the national level, there was no evidence of a lengthening of commutes for workers and employees in France between 1984 and 2006, and it was lower for these social categories than for the wealthier groups, from 2006 to 2013.

The debate on the role of amenities in land take

As noted above, amenities play a role in the choice of household residential location, most often in addition to housing and transport costs. However, they can play different roles depending on the scale at which they operate. Their role can be distinguished at the intra-urban space scale (between urban and peri-urban areas), at the regional scale (between urban areas) or at the French national scale (between areas of high environmental value and other areas).

Amenities and the intra-city spatial balance - between urban and peri-urban areas

Population growth and land consumption per household are two factors contributing to land pressure. Spatial differences in land pressure due to amenities therefore depend on the influence of amenities on the above factors. Environmental amenities, classically characterized by their distance from the city centre, can influence urban patterns. When these amenities, which are more pronounced at the periphery than in the centre, are taken into account, the land price function of household demand does not necessarily decline with further distance to the city centre. Households are willing to bid for locations far from the city centre despite higher transport costs, which reflects their 'willingness to pay' for these amenities. This may explain the emergence of a fragmented form of residential development. However, in most case, prices paid for land by households and businesses remain higher in city centres.

Urban green spaces are usually seen as attractive amenities

This analytical framework can also be applied to the role of urban amenities, which are most often 'historical' or 'modern' but can also take the form of 'natural' amenities located in or close to the city centre. Numerous studies, based on the breakdown of property prices into 'hedonic' prices (i.e. calculated on the basis of all of the characteristics that comprise the property) agree on the high value of urban green spaces and their potential role in the renewed appeal of city centres. The introduction of urban green space, which is known to mitigate the environmental impacts of urbanization, could also favour the reconcentration of housing and thus limit the spread of land take, however it raises other problems (Box 5.5).

Box 5.5. Controversies concerning the compact city

Compact cities are encouraged because they reduce some of the environmental impacts of urbanization (see Chapters 2 and 3) and preserve land. However, where densification is achieved by increasing building heights – sometimes to the detriment of the well-being of the population and resulting in building costs often considered prohibitive by developers – densification by filling in the available space (*smart growth*) will still change land use.

Moreover, on a more local scale and without specific design features, these two approaches alter the quality of the urban environment itself due to reduced sunlight, increased runoff, creation of heat islands, and reduction of amenities associated with open spaces. Nevertheless, densification is a stated objective of many land use policies in the majority of OECD countries (2017).

However, since they are public resources, natural areas, parks and gardens can generate negative externalities (sources of noise, nuisance and crime). This is particularly true in less desirable neighbourhoods. Laille et al (2013) in a review of the literature, showed that nearly one in six hedonic studies recorded negative amenity values for green spaces in cities. It therefore depends on whether the space is integrated into an urban policy (developed, maintained, monitored) or left abandoned. This also raises the question of how urban spaces included within a green network are actually perceived.

The limits of peri-urban amenities

Except for certain, noteworthy locations, peri-urban amenities sought by residents are mainly natural forest and agricultural amenities. However, living in these spaces also means artificializing them, which modifies the option value of the surrounding areas. Indeed, the urbanization of a parcel changes the probability of urbanization of adjacent parcels because their residential use value has decreased. The inhabitants of a peri-urban area thus 'harm' each other through their residential choice. A construction of peri-urban landscapes thus emerges which results, on the one hand, from the location choices of households, who seek space and proximity to agricultural and forest landscapes, and, on the other hand, from the degree to which agriculture is profitable. The amenity value of the last areas to be urbanised may be low enough that they are not developed, giving rise to a mixed area where residential and agricultural use coexist, a characteristic feature of many peri-urban areas created by individual housing.

This coexistence may cause conflict between urban dwellers and farmers in peri-urban areas. These conflicts are numerous, and vary depending on the intensity of differing nuisances generated by each group. In this event, some large farmers use economic and lobbying power to attempt to influence policies that promote their development. However, most often these agricultural activities tend to retreat from the urban fringes to avoid some of these conflicts.

When amenities are more specific and localized (for example, along the shorelines of coasts, rivers or lakes), the use of space per household around these sites is lower due to higher land prices. Population densities are also higher. In addition, high land prices lead to social segregation. When these amenities are located far from the city centre, or the amenities of the peri-urban area prevail, then the shape of the city extends towards the amenity areas (often discontinuously), thus leading to urban sprawl.

The role of amenities in the spatial balance between cities and/or between regions

The two traditional determinants of demand are housing prices (intrinsic characteristics of housing) and wages (characteristics of employees), however amenities are important determinants of quality of life. Thus, we can show that, in cities with sunny climates, housing prices are, all else being equal, higher while wages are less important. Conversely, cold and wet or particularly hot climatic conditions lead to lower housing prices and higher wages, which compensates for living in unpopular locations. While natural and climatic amenities play an important role in inter-metropolitan choices, at the intra-metropolitan scale, the social, cultural and recreational amenities define quality of life.

Natural and climatic amenities have a greater impact on population growth than on employment growth. The same applies to water-related recreation amenities. Moreover, the growth in the proportion of forest cover encourages incoming migration but, when this proportion exceeds a certain threshold the effect is reversed, and the increase in forest cover acts as a negative externality. These amenities can therefore play a significant role in mobility between cities or towards areas of high recreational and/or environmental value. In addition to working people who have or are looking for employment, these natural and climatic amenities partly explain the migration of retirees, whose residential location is determined by accessibility to the services they need. Similarly, these amenities play a key role in the development of tourist areas. Foreigners are strongly attracted to France for its natural amenities, including the sun and the sea. These 'lifestyle' migrations primarily involve retired people. Since the 1990s, numbers have grown as a result, among other things, of demographic ageing, increasing collective wealth and the new interurban mobility of the labour force.

Similarly, these amenities play a key role in the development of tourist areas. In addition to the establishment of the recreational facilities needed in these areas, a form of land take is developing, largely ignored in the scientific literature, through second homes, either because of their construction or because of the increase in land pressure that they bring. These second homes numbered 3.3 million in 2016 (or 9.5% of all housing), and their numbers are growing rapidly, although their growth (+0.8%/year between 1986 and

2016) was less rapid than that of principal residences (+1.1%/year over the same period) (Arnold, 2016). The artificial footprint of this type of housing has therefore increased substantially and should be considered more fully in analyses of land take (see Chapter 7).

Therefore, tangible and potentially important links exist between local (demographic and economic) growth and amenities, which can feed into local development policies based on the latter. However, ongoing climate change could, by altering this spatial balance, have consequences for the distribution of land pressure. In the United States, Rust Belt cities such as Cleveland, Detroit or Pittsburgh, could regain their attractiveness compared to Sun Belt cities such as Phoenix or Dallas, if the latter become exposed to excessive heat and periods of drought.

Land and property policies to limit urban and peri-urban sprawl

Studies on land and real estate markets reveal the need to distinguish how they adjust within monocentric cities and at the scale of the peri-urban periphery, in order to better identify the tools and levers likely to influence household location strategies.

Land and housing markets adjust to the demand for land and housing expressed by households. They are characterized by the following rules:

- The price of housing decreases as distance to the centre increases.
- The optimal lot size increases with increasing distance from the centre.
- The density of occupation decreases with distance from the centre.

What tools are available to influence household density and spatial distribution? While zoning and taxation are the traditional approaches (see Chapter 7), other tools such as markets for building rights or the purchase of land by local authorities can also be considered.

Transfer of building rights

The transfer of building rights is an economic tool that can influence land and property markets. It allows the developer to increase the density on a plot of land by buying unused rights on another plot in the same area.

The effectiveness of this type of regulation in limiting new construction depends on several factors. In particular, the intensity of additional constructions to which builders can aspire must be higher than under a conventional uniform regulation scheme. The area subject to this type of regulation should correspond to the expectations of the local community, the density limitation threshold should be strictly applied and the territory should not have unregulated areas that would offer developers alternative opportunities for new construction.

The establishment of a market for tradable building rights is hampered by the fear of concentrating damaging activities (extreme density in a single location) or by risking an effective reduction of the total quantity of buildings compared to a more conventional uniform regulation system.

In France, the use of this tool is negligible: the lack of a market sufficient to set consistent prices, legislative constraints and the prior authorisation system in place partly explain this situation. It could possibly develop under the impetus of the ALUR law (2014) which created a mechanism for transferring constructability in areas that need protection on the basis of their landscapes.

Land purchases and development projects

Public policies can act directly, in the form of land purchases and development projects. This is the case of the Green Belt around London. These green belts (see Chapters 7) exist in several countries but their application in the United Kingdom is unique in that they are decided by the agglomeration and imposed on municipalities. The British objective is ambitious: to limit urban sprawl, reduce the impact on agricultural areas, and avoid peripheral travel by discouraging settlements beyond the belt. On this last aspect at least, the objectives have not been met and the results of this policy are debated within the literature.

The anticipated effects of greenbelts include restrictions on construction and prices, improved environmental amenity on and around the site, and scarcity of supply relative to demand. In France, some studies show that such belts would have a protective effect on and around the target area, while attractiveness is enhanced on a broader scale. At the same time, the scarcity effect causes prices to rise and changes the demand for housing, directing it to other locations.

Enhancement through urban renewal, in turn, helps to maintain and attract people to urban centres. This can take the form of projects, defining renewal areas or renovation-renewal programmes for housing in disadvantaged neighbourhoods. The implementation of major public projects (transport, green spaces within cities, etc.) helps to reorganize neighbourhoods by encouraging developers to concentrate their actions close to these new amenities rather than on the outskirts. Potentially on a large scale, these projects require, as has been shown, that local authorities have a strong administrative management capacity.

The problem of vacant spaces and their conversion is understandably at the heart of many urban strategies[13]. Although rarely explored in the scientific literature, the main causes of vacant lots are their size, shape and location, as well as the cost of conversion linked to the nature of previous uses (dilapidated housing, industrial or military installations, etc.). Residential mobility also contributes to vacancy, as does the geographical capacity of a city to expand. The phenomenon is also cumulative: vacant dwellings or the presence of abandoned land give a signal of neglect that may eventually lead to further deterioration of the

13. It is very difficult to fully assess the artificial surfaces affected by this vacancy. It obviously concerns housing, and we know that the number of vacant dwellings in France has risen sharply, from 1.8 to 2.8 million dwellings between 1986 and 2016 (Arnold, 2016). The inventory of industrial wasteland and vacant office space remains to be carried out.

neighbourhoods in question. In the event of signs of decline in certain neighbourhoods or, more generally, when a city is neglected, a proactive public policy makes it possible to anticipate this phenomenon in order to better counterbalance it, especially as the rehabilitation of degraded neighbourhoods increases the value of real estate in neighbouring neighbourhoods.

Intervention is a key factor in identifying areas likely to form the basis of new networks of multifunctional travel and green spaces. The assembly of vacant, open spaces ('hollow teeth') requires incentivising policies that enable owners to cooperate, by granting higher densification permission in targeted spaces. If necessary, these policies would be complementary to the actions carried out by public land institutions through the exercise of their pre-emptive rights.

In already-dense urban areas, public needs (in terms of infrastructure, traffic, building quality, etc.) are high, and the management of this complexity carries costs. These obstacles are amplified on brownfields by the need for environmental studies, the identification of the entity responsible for the pollution, the duration of the project, etc.

In areas ignored by the private sector, it is the responsibility of public authorities to ensure urban renewal. Although urban policies are rarely responsible for the increase in vacant land, policies to encourage their reuse should be implemented. In the case of shrinking cities, these spaces provide opportunities to modernise the city, and include new environmental and energy standards. The choice of the type of redevelopment (green space, paths, housing) must be carefully studied according to the existing urban fabric and density. The well-being of the inhabitants is an important tool with which to limit the increase in vacant land in urban areas.

Forces for change through 'substitution effects' are emerging. In Scotland, for example, green belts are accompanied by policies to densify areas by targeting the conversion of polluted sites. In France, contractual tools such as the *zone d'aménagement concerté* (ZAC) can be used to require the reconversion of strategic spaces in local urban plans, which the private market ignores.

Transport policy: a key element for compact urban development

Transport policy often aims to create peri-urban secondary centres as multimodal transport platforms and hubs, one of the objectives of which is to reduce the dispersion of housing in peri-urban areas, but the results remain unclear. Although these mobility hubs make peri-urban sub-centres more attractive (especially residential), the reduction in the dispersion of housing has not met the expectations of decision-makers. Some experts advocate the implementation of *Transit Oriented Development* (TOD), consisting of the co-ordination of public transport policies with development policies, in order to increase the use of public transport and encourage more compact urban development.

While the operation of markets tends to concentrate the location of businesses in a given area, the deployment of transport infrastructure can bring about dispersion in the location of these activities.

Conclusions and policy tools

Household location strategies reveal a trade-off between numerous parameters, resulting in urban sprawl and/or peri-urbanisation of households. The latter, which does not always occur is, because of the type of housing to which households aspire, a strong source of land take within the vast areas that are today under the influence of cities. Limiting the extent of land take is as much about constraining the extension of the city's borders as it is about effectively managing its spread in the peri-urban municipalities. From this observation, public planning strategies are emerging as tools for working towards a better social balance and taking better account of the multifunctionality of cities. Urban models form the basis of much discussion through the questioning of social as well as environmental limits of compact city models, leading to some debate on the objectives of densification. On the other hand, the rehabilitation of vacant spaces, including industrial wastelands, within already urbanised areas appears to be an effective means of responding to housing demand and, moreover, a source of positive externalities for surrounding neighbourhoods.

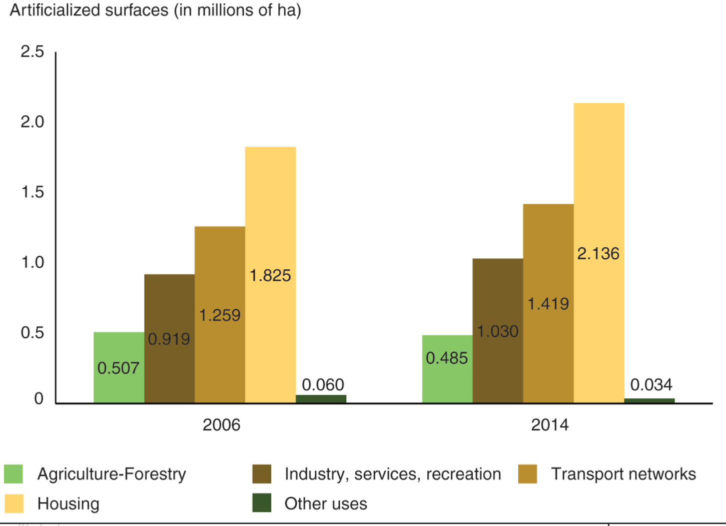
For public authorities, amenities can be seen as a catalyst for local development, the complexity of which is, however, well-documented. In intra-urban areas, as mentioned above, the development of ‘natural’ amenities can help to attract residents, knowing that these same amenities can also help limit the environmental impacts of land take. Natural amenities can also be the focus of the development of tourist activities which, in addition to their economic role, have an impact on land take via the extensive development of second homes and other tourist accommodation.

Ultimately, the challenge for public policies is to be able to respond to a twofold challenge: to limit the environmental impacts and spatial extension of artificialization linked to housing, while responding to the different forms of housing demand and the needs of the fight against inadequate housing.

6. Determinants of land take by enterprises and transport infrastructure

Alongside housing, the location of companies and the construction of transport infrastructure are the two other drivers of land take in France. According to Teruti-Lucas, businesses and infrastructure account for the majority of artificialized land (Fig. 6.1). Thus, industrial, commercial and public service activities accounted for 20% of artificial surfaces in 2014 (the 9.5% of artificial land linked to agricultural activity can be included), while transport infrastructure (road and rail) accounted for 28%.

Figure 6.1. Commercial areas account for one third of artificial surfaces.



Source: Teruti-Lucas.

According to Teruti-Lucas, the rate of growth of artificial surfaces between 2006 and 2014 appears to be less pronounced for these activities than for housing (see Fig. 5.1 above). Nevertheless, in a comparative analysis of 15 European urban areas (including Lyon, Marseille and Grenoble), Kasanko *et al.* (2006) show that, with the exception of two of them

(Dublin and Palermo), non-residential areas grew faster than residential areas. Moreover, the increase in this type of land take is almost systematically coupled with complete soil sealing, in contrast to what is happening in the case of housing (see Fig. 5.1, previously).

Business and industry location strategies

In Europe, as in all industrialized countries, there is a strong concentration of economic activities in and around large urban centres, which has long been the focus of spatial, regional and urban economics and economic geography. However, as will be shown below, the literature dealing with the consequences of the economic activity footprint, and therefore on their contribution to land take is surprisingly sparse, compared to the proportion of total land take by firms. However, some research has been found in respect of activities that consume large amounts of land, such as commercial or logistical activities. As the latter appear to be better documented, the following will focus on the development of these logistics facilities.

Economies of scale and agglomerated economies: sources of urbanization

The quest for economies of scale in production, accentuated by technical progress, is the basis of the concentration of economic activity and therefore of both urbanisation and metropolization. However, economies of scale (in this case, within a firm) are not solely responsible for the continued concentration of economic activities. Beyond the growth in the size of firms, various forms of so-called agglomeration economies have been identified. Market relationships, with respect to both goods markets and labour markets, play a significant role in the locational choices of firms. In response to transport costs and the impact of the types of competition they face, firms will seek to locate themselves close to their markets, both within and outside of their production process. They will therefore tend to cluster either as close as possible to their suppliers (intermediate goods markets), or as close as possible to their customers (final markets), or close to both at the same time. Concurrently, and while they do tend to attract workers looking for work, firms will seek access to a labour market large enough to recruit the labour they need, and thus establish themselves close to population centres. The reduction in transport costs over time, particularly with the advent of efficient railways and steamships, might have challenged these mechanisms. However, this decline in transport costs has had little impact on labour markets and has expanded the areas of potential markets.

In addition to the increasing returns internal to firms and the agglomeration economies that flow by way of markets, the increasing returns external to firms are also a source of agglomeration. These externalities combine several dimensions: that resulting from services to numerous and highly specialized enterprises; that of a specialized workforce allowing a good matching of supply and demand in the labour market; and finally, that of the emergence and diffusion of new ideas and thus innovation, which close proximity allows through 'face-to-face' contact. These agglomeration efficiencies can be divided into two classes: those achieved through the co-location of different firms or institutions operating in similar or related fields, commonly referred to as 'locational savings'; and those achieved through location in a large city, commonly referred to as 'urbanization savings'. Locational savings, specific to the industry sector to which the industry belongs are driving, for example, the aerospace industry to cluster in particular cities. In France, the largest concentration in the aerospace industry is not in Paris, but in Toulouse. The pharmaceutical industry in Lyon is another example of an industry that is concentrated mainly because of locational savings, notably due to the presence of a pool of specialized and experienced workers and training and research institutions.

This distinction between two categories of agglomeration economy has been reconsidered more recently in order to more precisely highlight the microeconomic foundations. This entails examining the role of market linkages in the agglomeration. Three types of mechanisms are now distinguished across all markets (labour, intermediate goods and final goods). They are considered to be crucial in assessing the benefits that firms enjoy when they locate in agglomerated areas: *sharing*, which refers to the sharing of indivisible goods and the benefits of diversity; *matching*, which increases as the number of people increases; and *learning* and innovation, which concerns the creation and dissemination of knowledge. The way in which each sector of activity mobilises one or more of these dimensions makes it possible to understand its degree of dependence on the agglomeration and its greater or lesser propensity to move away from it.

Beyond the debates and studies that continues to identify the relative weight of these different factors, their evolution over time and their sustainability, these different mechanisms have resulted in the trend towards metropolization. This movement is well known and is based on the tide of globalisation as well as on the power of agglomerated economies and the contraction of 'space-time'. This metropolization trend is a global phenomenon, drawing a relative concentration of innovative social and productive patterns in the largest cities. These cities are therefore the main drivers of economic, scientific and social development. In France, these mechanisms are responsible for a geographical rebalancing, marked by the growth of the main regional metropolises, but which remain articulated and coordinated with Paris, so that the latter maintains its status as a global city. Thus, in 2012, Île-de-France, which covers just 2% of France's metropolitan territory, was home to 19% of the French population and produced 30% of the nation's GDP. This geographical concentration of industry, accompanied by a fiscal policy that provides incentives, has facilitated the country's economic growth which, above a certain threshold, has enabled income to be redistributed to as many people as possible, as well as the financing of a range of public services that have contributed in France, and more generally in Western Europe, to a significant increase in household living standards.

There is no sign of a weakening of the economies of agglomeration for the vast majority of business sectors. In none of the countries where 'post-industrial societies and cities' are emerging is there a decline in levels of urbanization. Thus, in France as elsewhere, future employment growth will continue to be overwhelmingly in metropolitan urban areas. The arrival of Information and Communication Technologies (ICT) has had no visible impact on the decentralization of economic activities and urban populations. The most information-intensive activities (finance, media, large offices, etc.) continue to be concentrated in the major metropolises.

Centralization (of production) and lower transport costs are two sides of the same coin. For mass production to be profitable, however, the producer must be able to deliver the product to customers at a reasonable cost. Obviously the development of Rungis was dependent on the construction of motorways, the arrival of refrigerated transport and other logistical innovations. The same reasoning applies to services, the only difference being that we are now dealing with the transport of information. At the national scale, the effect of ICT, like earlier transport innovations, favours the strengthening of agglomeration forces.

Similarly, at a smaller scale, transport and new communication technologies, far from contributing to the dispersion of activities through lower transport costs, help to reinforce polarisation. Indeed, transport and information and communication technologies are based on the principle of mass movement in order to implement the economies of scale specific to them (large aircraft or giant ships). This consolidation involves the concentration of traffic by means of *hubs* that are similar to vast suction and delivery pumps. The world's largest airports and seaports are also located in the world's largest metropolises, which act as *hubs*. Thus, on a global scale, just one hundred cities, which account for only a fifth of the world's urban population, account for nearly 45% of air passenger traffic, 70% of airport cargo traffic and 70% of sea containers handled!

Likewise, the backbone of the Internet lies on the sea floor thanks to nearly 300 submarine cables, the most powerful of which are capable of providing tens of millions of simultaneous connections. Their geography on a global scale is organized in major east-west axes between global economic hubs, secondary north-south links, and with virtually non-existent south-south links as yet. It is therefore primarily the world's major coastal cities that are interconnected, further accentuating the effects of polarization.

Distribution of activities within the urban framework and urban areas

The dynamics of concentration-exclusion applied at the urban scale

The increasing concentration of the most intellectually-intensive professional activities (often the most highly paid), in the largest cities drives up wages and land prices so that companies requiring more extensive areas of land and not necessarily a highly skilled workforce will find it advantageous to locate in smaller cities or sparsely populated areas. The latter dynamic particularly applies to manufacturing industries focused on standard products.

The dynamics of concentration-exclusion also apply at the scale of the urban area, with the difference being the dynamics of land ownership rather than wages (or other local conditions) that will encourage companies to decentralize. Indeed, the primary function of an urban area is to constitute an integrated labour market. It is the residence-work interactions that define the urban area's perimeter, which is more or less extended depending on the ease of travel.

The causes of urban growth must be distinguished from the causes of urban sprawl. Innovations in transport and communications facilitate the concentration of economic activity at the scale of countries and continents, but also facilitate the emergence of larger cities. Transport networks, mainly via concentric and radial motorway networks, allow very high accessibility at the scale of the urban area with short journey times at a low cost. They therefore enable residents or businesses to free themselves from the high land costs that characterise urban centres by locating on the outskirts. Rungis serves as a useful example. Innovations in transport and communications have facilitated the concentration of food distribution to the Paris region, but have also facilitated its deconcentration within the Paris region, which, as a result, has expanded. The net effect of this dual dynamic of concentration-deconcentration on the overall demand for artificialized land is not easily measured.

An increasing number of towns and secondary cities are part of regional metropolitan systems. The consequences of this evolution are both a fragmentation of residential systems and a spatial reconfiguration of productive systems. At the scale of cities and territories, distances – including long distances – are increasingly less of an obstacle to daily interaction, the multi-location of activities and people is developing, and city boundaries are not disappearing but rather changing in nature - they cross territories internally more than they delimit them.

Companies play a major role in this reconfiguration. While consuming land (Fig. 6-1), they influence, by their location, a large number of other locational choices: the emergence of fringe cities in the United States, for example, means that sprawl no longer takes place around the city centre, but from secondary centres born of the redeployment of economic activities.

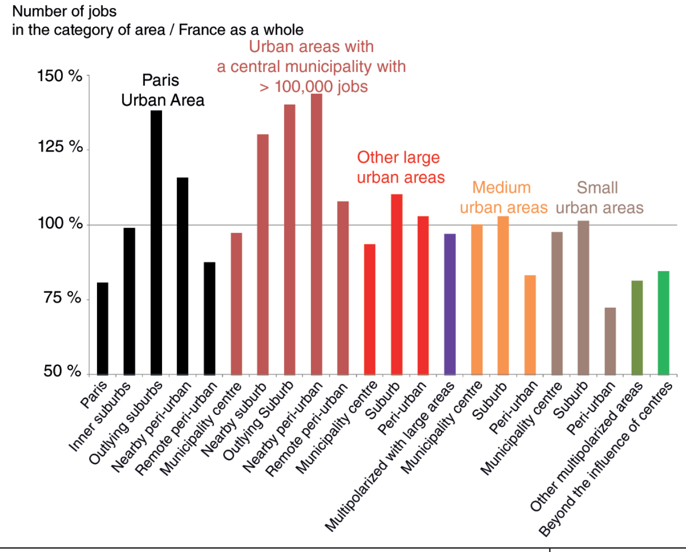
Urban and peri-urban sprawl of economic activities

The spread of populations at the city level has also been accompanied by a spreading of jobs. The rate of employment growth is now much more marked in the peripheral and peri-urban areas of large urban areas than in the centres of the major urban centres themselves (Fig. 6.2), irrespective of the urban centre under consideration (Fig. 6.4).

While jobs remain less decentralised than populations, the 'de-densification' of employment centres has been a major phenomenon in recent decades. Studies also show a strong correlation between the gradient of employment density and that of population density.

This trend can be explained by stronger growth around peripheral areas. Thus, in the United States, the majority of employment growth between 1985 and 1995 benefited rural areas. Moreover, the competition between outer suburbs, peri-urban (exurban) areas and rural areas would now form a more relevant area of research than competition between city centres and peripheries, given that the latter is self-evident.

Figure 6.2. Relative change in employment from 1982 to 2008 according to the centre-periphery gradient.



Source: Sénat, 2012, INSEE.

Polycentric cities or regional systems: two types of employment reconfiguration around cities

The dynamics of land markets within the city can lead companies to choose to locate on the outskirts to benefit from cheaper land without reducing their access to employees and consumers. The decisive element in this case is the synchronisation of the decisions of the initial economic actors moving towards the periphery, since this is what will ensure that companies moving to the periphery will maintain their access to local markets. This underlines the role of meso-actors (at the level of a sector of activity) in this synchronization. On the other hand, shifting employment to suburban or peri-urban areas can significantly lengthen workers' daily commuting time, depending on the accessibility of the areas. Studies also show that the addition of infrastructure far from the centre - for example, a ring road - contributes significantly to the continued increase in land consumption for economic purposes.

The growth of metropolitan centres eventually reaches the surrounding towns and medium-sized cities to form an integrated regional system. These dynamics are rarely reflected in public policies: the inter-municipal approach remains confined to the municipalities adjacent to the urban centre, and the ‘metropolitan centres’ mostly support relations between large metropolises. Apart from a SCoT, there is no simple way for a large metropolis to maintain a framework for dialogue with the medium-sized cities on its periphery. This is the thinking behind the Territorial Conferences of Public Action, created by the MAPTAM law, but this approach is not yet fully operational. Peri-urban areas remain aspiring territories, while urban fringes are pioneering fronts. Development projects have yet to be invented to a large extent in these areas in order to transform them into project territories.

The preservation of amenities: a desirable feature for companies

In the literature, amenities are rarely assumed to have direct effects on businesses and entrepreneurs. This is because amenities generally do not directly affect their production, except in the recreational sectors, which are very large consumers of artificial spaces (6.67% of artificial surfaces). On the other hand, they can have indirect effects via land prices, wages and the abundance of skilled labour. As agglomeration economies play a fundamental role in the location of service and high-tech companies, for cities of equal size and offering similar urban economies, amenities can play a role in growth to the extent that they attract skilled labour. They will be able to offer lower wages while paying higher rents. Residential amenities therefore play a role in the attractiveness of regions for businesses, and therefore have an impact on land take.

Studies show that the attractiveness of amenities for skilled labour plays a major role in medium-sized towns, but not decisively in large cities where agglomeration economies are largely dominant, nor in rural areas where, on the contrary, these economies are too small to be compensated for by amenities. On the other hand, amenities can play a supporting role. By attracting labour, they can make it easier to set up businesses. In dense areas where agglomeration economies are important, combating the negative externalities linked to density can be a complement to economic incentive policies.

The land consequences of the locational choices of companies: a gap in the literature

None of the aforementioned processes that influence the choice of geographical location for companies explicitly refers to land, as though it was unnecessary to use land to install the buildings. To understand this absence, one must realise that, contrary to the case with households, the cost of land is considered to be of negligible importance when choosing a location for a firm in comparison to the weight represented by all the gains that firms make from agglomeration. Thus, except in the case of activities that consume large amounts of land, such as logistics platforms, the spatial, regional and urban economies and economic geography cannot fully explain the land footprint of economic activities and its drivers, despite their importance in land take.

However, there is a direct link between the dynamics of companies, their sectoral/functional specialisation and their distance from the metropolitan area, with a direct consequence of reorganisation (or multilocation) on land consumption. From this perspective, the massive outsourcing of activities and the ever finer segmentation of sectors and branches results in more complex land dynamics. The specialization of peripheral centres makes them more sensitive to sectoral economic cycles and changing organization structures. This potentially makes the demand for land on the periphery more unstable than in the centre. As the development of a city involves differentiated growth among its different business activities, neighbourhoods are likely to experience different growth dynamics: while the centre will have a relatively stable demand for land, each peripheral zone can face very strong variations according to local sectoral circumstances. The consequence is that one peripheral zone may be under tension and be artificialized while at the same time on the other side of the city certain zones are empty, and that same barely artificialized zone may suffer an economic backlash that will see it turn into unused wasteland.

The establishment of logistics platforms: a land-consuming sector

Freight transport and logistics have developed rapidly in metropolitan areas, as can be seen from multiple indicators, a significant one of which is the number of warehouses and, more generally, buildings dedicated to logistics functions. Behind the issue of the location and size of these warehouses, it must be kept in mind that the artificial surfaces generated by their establishment extend beyond their simple occupation of the land (car parks and access roads).

The majority of warehouses are still isolated or within multi-purpose business parks, but warehouse *clusters* are now part of the logistics property landscape. A logistics platform is spatially delimited and generally enclosed. These parks reduce the nuisances linked to the logistics system of the regions they serve, in particular because they favour the relocation of transport and logistics companies to a single location, thus minimising logistical sprawl. The recent *Atlas des entrepôts et des aires logistiques en France* (Atlas of Storage Facilities and Logistics Areas in France), published in 2015 by the Ministry of the Environment identifies ‘logistics areas’, including ‘dense logistics areas’ and differentiates them from ‘isolated warehouses’ as follows:

- A logistics area is an area composed of at least three storage facilities or logistics platforms (EPLs) of more than 5 000 m^2, and within which, each EPL is located within six kilometres of another EPL in the same logistics area. These areas contain 81% of the EPLs of more than 5,000 m^2 and are located around the major French conurbations. The three large logistics areas around Paris, Lille and Lyon account for 23% of the EPLs over 5,000 m^2.
- In total, 19% of the EPLs are located in territories with low densities of logistics facilities. Almost half (46%) of these so-called 'isolated' EPLs are operated by manufacturers and are on average smaller (15,800 m^2). Thirty-six per cent of them are located in rural areas and 20% in urban units with fewer than 2,000 inhabitants.

The location of logistical storage facilities has undergone considerable evolution, and responds to factors linked to urban configurations. The spread of these facilities requires planning strategies to address this issue on an ad hoc basis.

Determinants of the location of warehouses

Three factors explain the increase in the number of warehouses in major cities: the outsourcing of logistics; the globalisation of trade; and the development of new urban consumption patterns. For example, e-commerce markets offer new services such as same-day delivery, which requires warehouses to be located close to major cities. These dynamic logistics services in large cities are carried out from buildings, known as warehouses, where shipments of goods are prepared.

Many of these modern warehouses are large and require extensive equipment (automation, information systems). The 'mega distribution centres', which cover 50,000 to 150,000 m^2, have developed since the 2000s. The location and layout of logistics facilities contribute to the efficiency of the distribution of goods, probably more so than the organisation of their transport, the costs of which have fallen dramatically over the last thirty years to 'almost insignificant'. The proliferation and expansion of warehouses and the preference for locating them in easily accessible suburban areas is due to the intensification of long-distance links between economies in widely separated countries.

'Platformisation' and dispersal of logistics terminals

The rise of 'logistics hypercentres', generally located at motorway, airport or rail interfaces, has strongly contributed to the emergence of specialized secondary hubs within a second belt around major agglomerations, particularly in the Paris region (Ile-de-France). A large number of logistics terminals are scattered over a large part of the metropolitan territory. For example, 645 of the 1281 municipalities in the Ile-de-France region contain logistics areas: 24 of them account for 42% of the utilised surface area, which suggests a high concentration in a limited number of municipalities. Conversely, 621 municipalities account for 58% of the surface area, an indication of sprawl.

The majority of mass distribution centres in Ile-de-France are isolated facilities or are mixed with activities other than logistics. Very few of these platforms are actually grouped with other logistics establishments. It is this fragmented landscape, but from which large concentrations of logistics activities are emerging, to which the Ile-de-France municipalities must react.

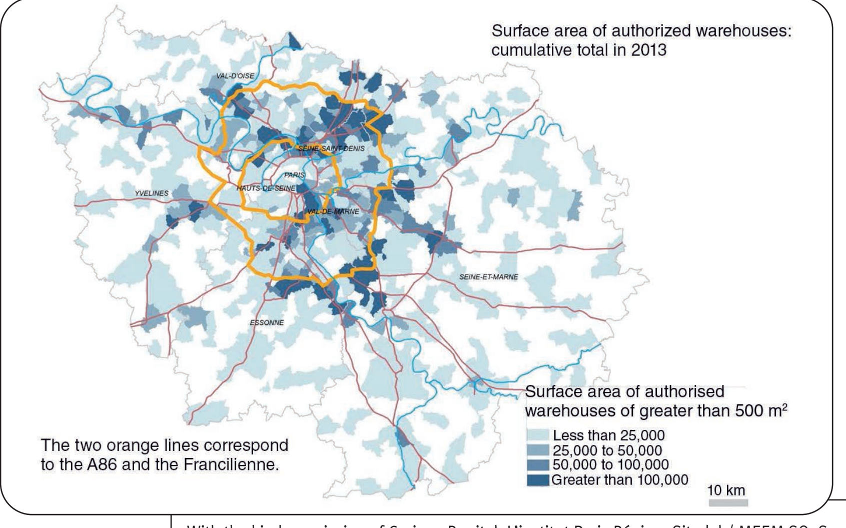
Box 6.1. Amazon® warehouses in Los Angeles

Online retail giant Amazon® has contributed to the growth of warehouses in metropolitan areas in the United States, especially on the fringes of major cities. In Los Angeles, three major distribution centres have been built since 2012 to serve the city, which was previously supplied from Arizona. Located approximately 110 km from the city centre (City Hall), these warehouses in San Bernardino, Moreno Valley and Redlands are 90,000, 110,000 and 65,000 m^2 in size respectively.

Instant delivery services (two-hour delivery) are also under development, and five city warehouses now operate in the dense fabric of Los Angeles. Whether in Atlanta or Los Angeles, the number of establishments classified as warehouses has tripled in the 2000s.

Since the late 1990s, growth in the number of establishments, and even more so in their total number of square metres, has exceeded 50 per cent for industrialized countries, and in some cases reach 200% (Box 6.1). This increase is particularly evident in large cities, demonstrating a metropolitan polarization of logistics functions. In the Paris basin (Fig. 6.3), the average distance of warehouses from the city centre fell from 155 km in 2000 to 110 km in 2012, thus narrowing around the Paris agglomeration. Within the Paris metropolitan area, however, these facilities have been subject to the process of sprawl.

Figure 6.3. Warehouse construction in Île-de-France, 1984-2013.



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Every day, to serve 700,000 establishments and 12 million inhabitants and to function as a national logistics hub, 800,000 deliveries and collections of goods are needed in Ile-de-France. The region also contains 20 million square metres of usable warehouse space, representing a quarter of the French stock. This Paris Region logistics base has grown at an accelerated pace in the recent period: between 2001 and 2009, the total number of square metres of warehouses increased by 50%. This relatively higher growth in logistics functions in large urban areas is explained by the economic needs of these areas. Urban areas offer 'a large local market for logistics services, proximity to infrastructure network nodes, an extensive labour market and an active professional real estate market' (Savy, 2006).

Logistic sprawl

While warehouses were traditionally located at the fringes of dense urban areas, or even within their core when linked to rail networks, they have moved to suburban and peri-urban areas, and closer to motorway networks and nodes and major intermodal hubs, particularly airports (and much less to river ports or rail terminals in countries such as France). These locations offer land or property rentals at low prices, which is especially important since the trend is towards very large buildings. A peripheral location offers more opportunities to build on large, level parcels, horizontality having become a very important asset for the construction of warehouses, in particular because of the constraints of installation of automatic storage and picking (gathering of parcels to be delivered) within warehouses.

In theory, this remoteness could reduce the total net distance travelled by trucks, since the destinations to be reached with deliveries (businesses and households) are frequently also far from city centres. However, the dispersion of logistics platforms is greater than that of other activities. Therefore overall distances to be travelled to deliver goods in the densely-populated Ile-de-France region have increased, but the savings in land costs and the efficiency gains made possible by a peripheral location broadly offset the additional transport costs for those deciding on new locations. On the other hand, this optimization leads to sprawl, with direct effects on land take and landscape transformation.

Box 6.2. Towards vertical spaces in the city centre

In Japan, municipalities allow multi-storey logistics buildings. The company Prologis® has built buildings of more than seven storeys in the heart of Tokyo, and in the immediate vicinity of residential buildings. The return of logistics activities to dense urban areas reduces the last few kilometres of delivery, increases the flow of products, and reduces the land footprint. For its part, the city of Paris has implemented a policy of returning warehouses to the city centre by supporting the creation of urban logistics spaces in central districts, and by reserving areas in its PLU (2016) to accommodate logistics operations, if possible with rail or river access.

The Île-de-France region has identified the types of logistics operations that can potentially be developed in densely populated areas, as well as the land and legal tools at its disposal. The planning documents (SDRIF, 2013; PDU, 2014) include objectives for the recentralisation of logistics. However, given the context of low transport prices and land pressure, it is expected that peri-urban development of logistics buildings will continue.

Logistics planning: governance needs to be clarified

The final choice of location for logistics platforms is the result of a bilateral relationship (sometimes highly unbalanced) between a logistics proponent and a municipality. In an attempt to regulate this process, France was one of the first European countries to ensure that merchandise was taken into account in urban planning documents, but it was not until the NOTRe law in 2016 that the SRADDET (*Schéma régional d'aménagement, de développement durable et d'égalité des territoires*) was created, and which is still being developed in many regions. Developed at a regional level, this planning document is based on the model of the SDRIF (*Schéma directeur de la Région Île-de-France*), that had existed since 1965. It aims to structure the regional area by focusing activities around twenty or so receiving sites that are well distributed throughout the Region.

However, institutional and constitutional obstacles are at play, insofar as the Region does not have the legal powers to directly constrain local urban development plans. Consequently, none of the past master plans could significantly influence the location of warehouses and distribution hubs in Ile-de-France. However, mechanisms do exist and the State could play a significant role, if only by exercising control over building permits. In addition, most logistics facilities are subject to the classified facilities regime, placed under the authority of the State. By this means, introducing this issue into the regulations could have a significant impact on the issuing of permits and thus influence the location of logistics terminals to create a more effective distribution of these facilities.

Transport infrastructure in France

According to the Observation and Statistics Service of the Ministry of Ecology (Janvier *et al.*, 2015), the total footprint of the rail and road networks in 2012 (last known date) was 20,970 km^2, or 3.8% of mainland France. This estimate is close to the European average, which exceeds 3% of land use among the Member States (EEA, 2005). Metropolitan France (excluding Corsica) thus benefits from the largest road network in Europe, with a total of 1.073 million linear kilometres (compared with second placed Germany with 644 million linear kilometres) (Janvier *et al.*, 2015).

Of the different forms of transport infrastructure, roads account for the largest share of land occupation with 1,230,000 ha, which is equivalent to the area of the Île-de-France region. Railway lines occupy second place with 867,000 ha, most of which comprises permeable surfaces. No estimates have been made for waterways. However, by comparison, the available literature that addresses the issue of the construction of transport infrastructure (road and rail) and their impact on land take, is also surprisingly sparse.

Calling into question the beneficial effects of transport infrastructure

The indirect effects of transport infrastructure (the so-called structuring effects) remain difficult to quantify because it is difficult to isolate the infrastructure from other factors involved in spatial and territorial recomposition. The numerous studies devoted to this issue unanimously dismantle the 'myth of the restructuring effects' that the post-war boom had created.

Infrastructure with no significant structuring effect

France has seen several waves of modernisation of its transport networks, two of which are significant. The first concerns the development of the railway network, initially with the national network between 1840 and 1860, and then with the local lines, via the Freycinet plan, between 1880 and 1914. The second wave began in the 1960s, when France began to make up for its lack of motorway infrastructure in order to reduce territorial disparities. Thus the link between transport and territorial development was established.

As the political, economic and cultural capital of France, Paris is the focal point of the French transport system. In the 19th century, Paris railway stations ensured the lasting pre-eminence of the capital in its role as a hub of the railway network. This was reaffirmed with the high-speed lines (LGV). In addition, motorways were built in radial alignment from Paris. Only from the 1980s onwards were transverse routes gradually built, thus changing from the previous radial network.

It is a fact that only the connections between Paris and the major provincial cities can economically support high-speed transport links. This is particularly true for high-speed lines, which require new infrastructure and high transport capacity. Their profitability can only be ensured by very large traffic flows, which exist first and foremost between Paris and the major provincial cities, and only secondarily between the latter. Hence a snowball effect occurs between transport and metropolization. Metropolises generate the largest flows, which justifies the location of the most efficient transport systems, which in turn reinforces the polarisation of the cities.

The major determinant of the construction of a transport infrastructure is first and foremost to meet traffic demand. But it in turn feeds this demand by expanding opportunities for accessibility gains. This is why it is necessary to question the link between transport infrastructure development and territorial development. There is no direct relationship between development and transport infrastructure (both road and rail). This infrastructure is a prerequisite, but not in itself sufficient. In the long term, they even tend to accentuate the prevailing trends, strengthening dynamic areas through the suction effect and weakening the most fragile areas, which become mere transit areas or at best recreational areas (Box 6.3).

Box 6.3. New interplay between stakeholders, and national disengagement: towards greater consultation

Cities and regions are increasingly involved in infrastructure financing, while the State's disengagement from territorial balance policies exacerbates interurban competition. At the same time, the development of consultation procedures is enabling local stakeholders and the public to participate more actively in the decision-making process. These developments tend to shift the focus from national networks towards issues of local accessibility and attractiveness and a more balanced trade-off between the approaches advocated by stakeholders with divergent interests.

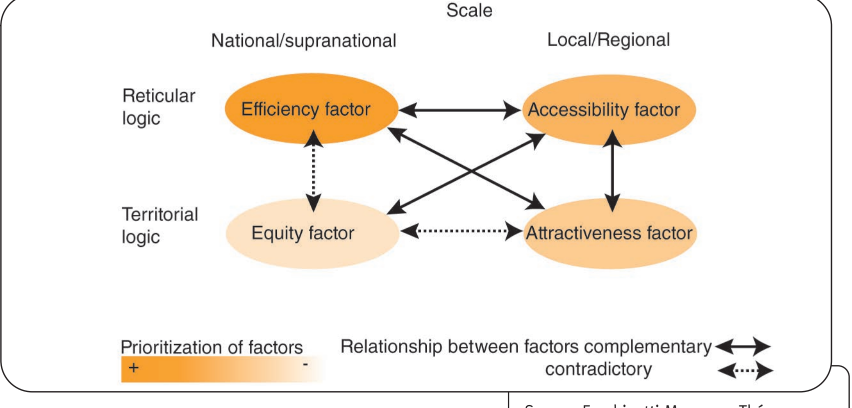
The acceptance of major transport infrastructure projects by the various stakeholders in a region is a central issue and has a direct influence on land take. Multi-stakeholder approaches are developing, and a high degree of collaboration and partnership between stakeholders is essential to the success of a project (Faivre, 2003). Similarly, in analysing the role played by the TGV Est (East) in the use of tourism assets in Reims, Bazin *et al.* (2010) show that 'collective adoption of innovation such as a high-speed service' and the ability of stakeholders to collaborate constitutes 'the key to the emergence of positive effects from infrastructure'.

A direct causal link between land take and transport infrastructure, apart from land take directly linked to the infrastructure itself, is therefore unclear. At a finer scale, transport infrastructure amplifies the territorial dynamics at work in France, thereby amplifying the phenomena causing land take in the most dynamic regions. At a larger scale, especially in urban areas, they are an essential factor and a condition of peri-urbanisation. Since the 1970s, motorway interchanges and major city entrances have gradually become favoured locations for commercial and business zones. The entrances to French cities now resemble long, uniform commercial corridors from one city to another, with severe landscape degradation.

A multiscalar approach to issues related to the development of new transport infrastructure

The development of large transport infrastructure places two divergent spatial rationales under tension, depending on the scale (Fig. 6.4). Reticular logic, which characterises network operators and their regulatory authorities, is based on optimising traffic supply in the name of economic efficiency at national and supranational levels, and accessibility at local and regional levels. Territorial logic, generally driven by local authorities for the general interest, responds to national issues of equity and solidarity and local issues of attractiveness.

Figure 6.4. Spatial rationales; complementary or contradictory, according to geographical scales.



Source: Facchinetti-Mannone, Théma, 2015.

Travel-time optimisation, which in the name of economic efficiency requires a consolidation of traffic flows along and through the most efficient routes and nodes, respectively, increases small-scale territorial inequalities and exacerbates the challenges of accessibility and attractiveness at a large scale. The discriminatory nature of travel-times reinforces the importance that cities and regions attach to a connection to the network, as evidenced by the numerous debates on the choice of railway or motorway routes, the choice of location of 'coveted equipment' such as TGV stations or junctions, or the establishment of services. Their location also shows that limiting land take is not a determining factor (the environmental impacts of transport infrastructure construction are dealt with in Chapters 2 and 3). Since accessibility is perceived as a guarantee of attraction, local stakeholders mobilise to obtain the best connection to the network in order to capture a share of the 'territorial effects' that are attributed to the contraction of travel-time. The challenge is to guarantee the population and the main traffic generators in the relevant territories efficient access to the macro-network, which is compatible with the economic benefits of large cities and metropolises (see Chapter 1.).

Models investigating the influence of transport infrastructure on land use

Multiple simulation tools have been developed to predict the influence of transport networks on territories. LUTI-type models (Land Use and Transport Integrated) appeared as early as the 1960s to understand the interactions between transport and land use. Numerous models exist under different paradigms. Urbansim, for example, has been used to test policies for the densification of urban fabrics in order to show the consequences on transport networks. They now use remote sensing as the main source for identifying direct and indirect land-use changes linked to infrastructure construction. This requires both a high level of typological accuracy of land uses (e.g. airport, commercial, highway, industrial building, residential building, public park - nature park, public square, railway corridor, land reserve, and water surface) and long-term land use change data.

The models measure the influence of the transportation network on land use change. Numerous studies have shown the correlations between the development of motorway networks and its impacts on changes in land use and population. Analysis of the evolution of Twin Cities (Minnesota, United States) over the period 1958-2005 shows, for example, that the probability of land use change increases with proximity to highways for commercial and industrial activities. On the other hand, this proximity has no effect on agricultural parcels. The probability of change is even negative for residential areas.

Conclusions and policy tools

Economic activities undertaken by businesses as well as transport infrastructure, play an important role in urban patterns and their location, which has a direct impact on land consumption. However, the land dynamics generated by the location of economic activities nevertheless remain complex and poorly documented in the scientific literature to such an extent that beyond their expected effects, particularly in terms of regional development, it is difficult to draw conclusions about the way in which they actually influence urban, peri-urban or more distant land dynamics. As a result, the identification of policy measures to limit the spatial extension of their footprint is extremely difficult, and they mainly rely on the rationale for the location of transport companies and infrastructure (with, for the latter, an element of control of their environmental impacts), without being able to assess the impact in terms of area consumed.

Major cities, and increasingly the Regions, represent the new spheres of governance, and planning appears to be an important tool that can better control land take. The distribution of activities on the outskirts of cities calls for a reconsideration of city centres by economic stakeholders, just as the development effect of transport infrastructure is now being called into question. Ultimately, the emergence of new sectors or the increase in factor productivity are likely to change the development rationale of the city sector by sector and thus the land use patterns within the city. Beyond the debate regarding whether or not to give priority to metropolitan areas in spatial planning policies, the public policy issues raised by these findings are unfortunately rarely studied in the literature. This is one of the areas where there is a need to undertake more advanced research.

Due to the metropolization of logistical activities, large urban regions have recently seen the number of facilities dedicated to these activities multiply and become spatially organised in a far more dynamic and centrifugal way than most other economic activities. These phenomena contribute to the efficiency of metropolitan economies by reducing the logistics costs inherent in complex urban spaces, but they do so with significant collective environmental damage. Integration of logistics activities in local planning documents would make it possible to better regulate their implementation and construction. The same is true at the regional level. Generally speaking, a physical grouping ('clustering') of logistics facilities in metropolitan and regional areas should be pursued, since the more efficient management of infrastructure that results allows for the consideration of multimodal equipment and architecture that consumes less land. Finally, the question of logistics platforms goes hand in hand with that of consumption patterns and their impact on land take.

Whatever the mode of transport, the factors that determine infrastructure projects are the result of a complex process that combines technical requirements with the constraints imposed by topography and environmental preservation. However, the final decision is made on the basis of financial criteria and political objectives. Thus, an examination of the history of major infrastructure project decision-making would be very useful, in order to better understand the choices made in the past, starting with the Ministry of the Environment's report on the evolution of linear transportation infrastructure. Moreover, research on land take by transport infrastructure focuses on urban and peri-urban areas, without taking into consideration the impacts on more distant areas. Consideration at the scale of urban units might also be relevant. In addition, broadening the scope and scale of impact studies prior to the construction of infrastructure would make it possible to consider impacts and nuisances more widely.

Roads represent the focus of the majority of research, while the high-speed rail network is growing. The effects of high-speed rail, including the rail network and location of stations, are often approached from an economic perspective with insufficient measurement of the impact of this new infrastructure on land use. It is therefore essential that regional science as a whole should address this issue. Conversely, local railway lines are regularly closed down. Thus, the question of 'reverse land take' and their reclassification must be raised because these create opportunities for biodiversity, as well as for soft modes of transport (greenways, cycle paths, etc.).

7. Avoiding or reducing land take, or possibly compensating for its effects

While a subject of intense political concern and considerable public debate, land take covers an extremely multifaceted economic and social context, making it difficult for researchers to fully grasp. By definition, artificial land comprises the surfaces on which all human activities take place (except agricultural and forestry activities). As it is used for housing, businesses, public services, transport infrastructure, etc., it provides many services to society. All of these activities tend to aggregate in cities which, more recently, have spread either by pushing back their borders, or by the 'peri-urbanisation' of more distant areas that are discontinuous with the city itself. At the same time, land take results in environmental impacts that vary according to the degree of surface sealing and the local arrangement of land with different covers, and on competition for the use of the same soils and/or land from agricultural (and forestry) activities.

Ways to limit these different effects will vary depending on the land use (residential, commercial or infrastructure), and whether the land in question is located in the city centre or dense suburbs (where the land is already completely artificial), in the immediate outskirts of the city (in the area where the city borders extend), in peri-urban areas (more or less densely populated) or in more remote rural areas (especially tourist areas). Thus, determining whether or not to limit the extent of artificialized land and where this should be achieved, while preserving the economic and social services this land provides, or whether to limit the environmental effects of land take, urbanization and urban sprawl, is not a simple matter. Public and scientific debates and disagreements on these questions are intense and difficult to summarise through a collective expert review. On the other hand, an analysis of the policy instruments aimed at these different objectives is necessary in order to examine their (possibly contradictory) approaches, limitations, and the advantages that they can bring.

Public policies and the laws created for their implementation contribute to the regulation of land take. Analysis of these reveals the imprecise and multifaceted nature of the concept of land take. Although strongly linked to land use planning and development, it is only recently that this phenomenon has become an issue for the State and local authorities. These policies not only strongly impact rural areas, but also cities, and particularly the socio-economic profiles of neighbourhoods. This chapter therefore aims to summarise them and also to provide a legal and fiscal explanation. The analysis reveals that these instruments, of differing ages, address three different broad objectives with varying degrees of success. The structure of this chapter is consequently arranged in a manner echoing the well-known three-part legal approach of the impact assessment mechanism: the first is to avoid or at least control land take, the second is to reduce its impacts, while the third, less established than the other two, offers prospects for compensating for land take. Firstly, however, the legal and fiscal pathways to land take are presented.

The legal and fiscal drivers of land take

An initial assessment reveals that, as a consequence of the lack of a specific definition of the subject of 'land take', laws and public policies such as taxation contain elements that directly or indirectly encourage land take, or more precisely, urbanization.

The legal drivers of land take

Land take is linked to ownership and the owner's control over the use of land. Its use is free, subject to the rights of third parties and provided that it is not used contrary to laws and regulations (Civil Code, art. 544). This implies that if there is land take, it is either that there are no regulations that opposes it, or on the contrary, that these regulations favour it and that, if necessary, the regulations are accompanied by financial and fiscal mechanisms likely to impact real estate markets.

The strengthening of litigation law in favour of urbanisation

The desire to increase the housing stock in order to meet housing needs has led to significant changes in litigation law, either to restrict the ability of applicants to appeal against a planning document or an urban planning permit, or to allow the judge to rule to legalise it. The law, for the most part, can be summarised as follows.

The petitioner, appeal deadlines and power of legalisation by the judge

The law has evolved in the direction of restricting the possibility of appeal by community or environmental organizations. Henceforth, an environmental protection association may not appeal against a decision if it has been taken before the association has obtained authorisation confirming its interest in taking action. Similarly, an organisation's action against an urban planning decision is only admissible if its articles of association were filed before the petitioner's request was posted.

While simply being a neighbour was previously sufficient to establish the admissibility of an appeal, the applicant must now need to demonstrate how they would be directly affected.

Changes to laws now limit the time for appeals against a project on the grounds of procedural errors or mistakes in the urban planning documents to 6 months, and judges are increasingly empowered to legalise these documents along with building permits (C. Urb. Art L. 600-9 and 5).

Restrictions on the demolition of illegal constructions

This penalty was based on an invalidation or claim of illegality found by the court within a sufficiently long period to allow the demolition action to be brought (five years), with a starting date for the statute of limitations (completion of the work). Following the Pelletier (2005) and Labetoule (2013) reports, two reforms will make this regime more complex and limit its scope. The demolition of buildings is now limited in time (six months, or two years in certain protected areas) and its conditions are framed so as to limit its application.

Housing construction: a constraint for communities

Certain regulations make construction compulsory. For example, the Local Housing Programme (PLH) requires inter-municipal authorities to meet housing and accommodation needs and to promote social mixing and urban renewal. This programme aims to spread the housing 'burden' between the municipalities comprising the inter-municipality, and thus to spread the burden of artificialization, if the project's plot of land was not already built on.

Some ways of reducing artificialization could be envisaged, at the cost of minor modifications to this programme. These include: making aid and subsidies conditional on efficient use of land, involving a prioritised search for land recycling and the submission of a report showing the situation within the municipality or inter-municipality; prioritising urban renewal operations, under the same conditions of demonstrating land availability; and regulating second homes (Box 7.1).

Box 7.1. Lack of regulation of second homes ('cold beds')

According to the INSEE criteria, second homes refer to accommodation used for weekends, leisure or holidays, as well as furnished accommodation rented (or for rent) for tourist stays, particularly on the coast and in the mountains (35% in Corsica and the Hautes-Alpes, compared to the national average of 10%). The regulations do not limit their construction, let alone prohibit secondary use of a building that has been built for the purpose of a principal residence.

Other countries have opted for a more radical solution, whereby second homes are prohibited once a certain ratio has been exceeded. This is the case in Switzerland, following the adoption of the Weber initiative. Thus, the Federal Law on Second Homes of March 2015 prohibits their construction in municipalities that already have more than 20% second homes, or would have more than 20% if the building permit applied for was granted.

The incentive effects of public housing policies on real estate markets

State intervention in housing aims to help the least wealthy households find housing while supporting construction. Direct state expenditure on housing amounts to about 41 billion euros or nearly 2% of GDP (Housing Accounts 2015). Studies on the impacts of these measures focus on their effectiveness in reducing social inequalities, and in particular whether households or enterprises relocate to targeted areas. They do not address whether or not they contribute to urban sprawl. These studies highlight the difficulty of countering the forces at work in the real estate markets and, in particular, the trends toward segregation and urban sprawl.

The SRU (Urban Solidarity and Renewal) law has the objective of achieving 20% social housing in urban areas with more than 50,000 inhabitants. It has had a significant and growing positive effect on their construction, with an increase in the proportion of social housing of 2.9% between 2000 and 2004 and 6.6% between 2000 and 2008.

Incentives for rental investment. Several schemes have succeeded one another since the Méhaignerie Act in 1986 (aimed at promoting rental investment, home ownership of social housing and the expansion of the land supply), with the aim of encouraging households to invest in new rental housing. The Scellier Act in 2009 excludes the densest and least stressed areas from the scheme. Studies show that these measures have not increased housing production, but rather have led to a 1% increase in prices in areas close to boundaries between areas included and excluded from the scheme.

The effect of the zero-interest loan (PTZ). Initially reserved for the purchase of new housing, it is now also available for the purchase of existing housing with improvements. The PTZ has had an inflationary effect on land prices: its more generous conditions have led banks to increase the volume of credit granted to home buyers, and much of this increase is reflected in higher prices.

Policies targeting certain areas have been developed to deal with major regional disparities. Subsidy schemes for particular areas may be important in particular cases. For example, where a disadvantaged population cannot move or relocate from an area of low employment, the provision of financial incentives directed at worker mobility may then be justified. However, these schemes are usually built into rents and recouped by landlords.

To encourage the establishment of enterprises in areas affected by unemployment, zones have been defined and classified, but studies show that the impact of these programmes on business and job creation is both limited and temporary in view of their high costs. However, these policies are more effective when the areas concerned have high accessibility.

The fiscal drivers of land take

Property taxation: aspects of the debate in France

Since real estate assets represent more than half of French people's wealth, any consideration of changes to property taxation forms part of the broader debate on optimal taxation of wealth, including its incentive and diversionary effects on other assets or sources of income. In France, the few discussions and developments within the subject are strongly marked by a context of tensions on the housing market. The priority should therefore be to modify the tax system by providing the right incentives to reduce the phenomenon of land banking, and increase the amount of land available for construction (Box 7.2).

Land banking is encouraged by a tax based on the historical cadastral rental values of land, which are heavily undervalued. This low taxation confers a high holding value on investment in undeveloped land, thus prompting the investor to postpone the sale of land for construction in anticipation of a price increase.

Box 7.2. Property taxation and city size: theoretical predictions and empirical results

The impact of a property tax on the size of cities can be broken down into two opposing effects on urban sprawl. On the one hand, an increase in property tax has a negative impact on the intensity of land development, which encourages urban sprawl, and on the other hand, increases the cost of housing per square metre and thus reduces housing demand in terms of space. This decrease in dwelling size leads to an increase in population density, and therefore a decrease in the expansion of the city. The net effect of a property tax increase is therefore ambiguous, but the trend would confirm that a property tax increase exacerbates sprawl.

The SRU law gave municipalities the option of increasing the property tax on undeveloped land. The municipalities that took up these cases applied very modest increases, with no real impact on behaviour. The Finance Act for 2013 has standardized and strengthened the scope of this surcharge (article 1396 of the General Tax Code) in areas where real estate tensions are highest, to encourage the release of land. Thus, in municipalities subject to the annual tax on vacant housing, the cadastral rental value of buildable land, after a deduction of 20%, is increased by 25% of its value and by a flat-rate value set at €10/m2 for taxes due for the year 2016 and subsequent years. The mandatory mark-up scheme in the most stressed areas, initiated in 2012, suffered from a lack of calibration, and its revision in 2016 returns to a lower level, which is unlikely to change behaviour.

In municipalities not subject to the annual tax on vacant housing and where existing public roads and networks on the outskirts of the area to be urbanised have sufficient capacity to serve the buildings to be established in the area, the stated rental value of buildable land located in urban areas or zoned for urbanisation may be increased. This increase may be used in the calculation of that portion to be paid to municipalities and public institutions engaged in inter-municipal cooperation but without their own taxation.

However, a reform of stock taxation must be accompanied by a reform of flow taxation. In other words, market fluidity can only be restored if building land transactions are taxed less heavily.

Finally, tax mechanisms available to municipalities and public institutions for inter-municipal cooperation (EPCI) exist to encourage companies to establish themselves in their territory (Box 7.3).

Box 7.3. Economic and fiscal incentives for business establishment

Land take can be stimulated by local authorities who seek to encourage industrial and commercial companies to set up in their territory, by using, when they are able, one of the 70 taxes that make up local company taxation. Another means is the provision of land at the symbolic euro rate. However, a report on local taxation and enterprises issued by the *Conseil des prélèvements obligatoires* in 2014 highlighted the fact that this taxation is only one criterion among many others that influence the choice of location for companies: the attractiveness of a region is mainly the result of its economic environment and the availability of land. This results in a form of land take that the community struggles to control, at the risk of foregoing the establishment of businesses on its territory.

Property taxation and development tax

In most developed countries, property tax is calculated by combining the value of land and the value of buildings. Since investment in real estate capital is price-elastic, there is no reason, other than practical, to tax it at the same rate as the land on which it sits. The practice of a single rate between land and buildings could be challenged: the taxation of land at a higher rate than buildings should encourage denser construction on smaller lots, and thus moderate urban sprawl.

The development tax applies to improvement operations, construction, reconstruction and extension of buildings, installations or developments of any kind subject to an authorisation system under the Town Planning Code. It is regularly presented as a fiscal incentive capable of regulating land take. A 2004 study of 29 municipalities near Chicago suggests that the introduction of such a tax is associated with a 25% to 30% reduction in the residential construction rate. Other results, however, were more mixed. In the State of Florida, no impact on construction rates in central or peripheral cities or in rural areas was observed.

In France, this tax was introduced in 2010 and is based on the value of the building surface. Notwithstanding the exemption of certain constructions according to their purpose, and a 50% allowance depending on the characteristics of certain premises, the rate of the municipal or inter-municipal share of the development tax may be increased up to 20% in certain sectors, if substantial road works or the creation of public facilities is then necessary. Thus configured, this tax appears more for the benefit of the municipalities than as a real tool to encourage a reduction in the use of land, since it was introduced in order to help finance public infrastructure in the municipality.

The tax might, however, be adapted to provide a genuine incentive, via:
- the introduction of variability based on indicators of soil quality or soil availability;
- differentiation according to whether or not the project involves previously undeveloped land, in order to increase the cost of projects on greenfield land. This solution may be accompanied by a tax reduction in urban centres and developed parcels;

• an exemption from the tax in the event of land recycling; a form of tax 'reward' in favour of the developer who rebuilds after demolition or after decontamination of a piece of land, thus avoiding land take elsewhere.

In this way, two pitfalls regarding the imposition of the tax should also be avoided. The first refers to a rate that provides too little incentive (but a high rate may not have an effect on manufacturers with sufficient financial capacity). Secondly, municipalities may be tempted to use it for general revenue-raising purposes, in which case either a special allocation in line with its purpose or allocation to another public entity should be provided for.

Mechanisms to avoid or control land take

In an attempt to limit the fragmentation of agricultural land and to control urban sprawl, the law provides a set of tools for controlling land take. The allocation of land to uses through zoning mechanisms distributes land use over the area, and is the tool most likely to prevent land take, although in practice there are many limitations. Laws and taxation are more effective, or at least better defined, when they apply to specific areas such as rural areas, mountains or coastlines. Finally, the objective of densification is a means of limiting soil artificialization, although its benefits from a spatial perspective must be weighed against the resulting environmental impacts.

Zoning: an effective tool to prevent local land take

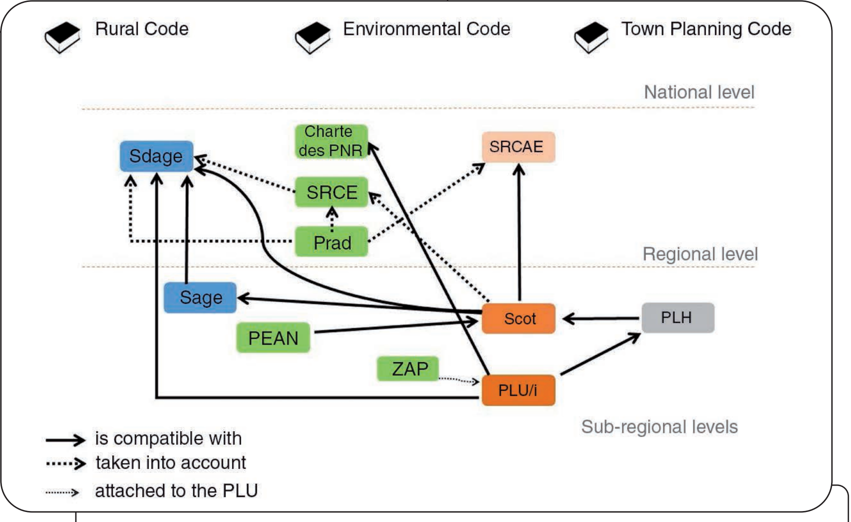
Zoning, mainly derived from urban planning law and environmental law, is used to distribute uses over a territory, but also to control residential densities and the land market. They are the spatial expression of multiple planning documents, the coordination of which is organized either through a compatibility report or a consideration report (Fig. 7.1). The objectives of the planner, in using one type of zoning rather than another, are therefore complex and do not presume an exclusive desire to limit urban sprawl.

Between a legal tool and its application as a policy, the effectiveness of zoning in preventing land take depends to a great extent on governance. On the one hand, decentralization allows a level of local governance that is more in touch with local contexts, while on the other hand, it exposes the decision-maker to pressures and ambitions that may challenge its effectiveness or relevance.

Do zoning schemes prevent urbanisation?

The measures for the prevention of urban sprawl are certainly in competition with those that allow land take. For example, limiting land take through the principle of continuous construction may be undermined by the existence of a local urban plan or a zoning map that delimits hamlets and continuous groups of traditional constructions or dwellings but which may be expanded, taking into account the traditional characteristics of the housing,

Figure 7.1. Compatibility and consideration reports of key planning documents.



PEAN: perimeters of protection and enhancement of agricultural and natural peri-urban areas; PNR: regional natural park; PLH: local housing plan; PLUi: local inter-municipal town planning plan; PRAD: regional sustainable development plan; SAGE: water development and management scheme; SCoT: territorial coherence scheme; SDAGE: water development and management master plan; SRCAE: Energy, Air and Climate Regional Scheme; SRCE: regional ecological coherence scheme; ZAP: protected agricultural zone.

the buildings built and the existence of roads and networks (L. 122-6). Moreover, the provisions on continuity do not apply when the SCoT or PLU includes a study justifying, based on local circumstances, that an urban development not in continuity with existing urbanisation is compatible with the objectives of protecting agricultural, pastoral and forest lands, with the preservation of landscapes and environments characteristic of the natural heritage, and protection against natural risks.

The use of exclusion zones, which are strictly non-constructible, limits urbanisation. In France, only strict environmental zoning (equivalent to IUCN categories I to IV) guarantees that no new housing will be built within ten years.

Some studies show that zoning has a direct impact on real estate supply (availability and price) and can lead to denser developments. The example of *greenbelts* (see Chapter 5) shows that these belts can also hold back urbanisation. The long-term effectiveness of these policies is ambiguous because they depend on local contexts and there is a potential acceleration of construction in peri-urban areas (Box 7.4). In general, the best results in terms of regulating new construction come from rigid zoning, accompanied by an effective system of control.

Box 7.4. Fiscal decentralization: the temptation to increase tax revenues

Most OECD countries are characterised by a high degree of administrative fragmentation at the local level. When this jurisdictional fragmentation is accompanied by fiscal decentralisation and a lack of co-ordinated economic governance, the conditions are in place for competition to occur. Competition is naturally exacerbated when local authorities have the power to tax companies, whether or not this power is linked to the value of the land being used for commercial purposes.

In Italy, the decentralisation of property taxation (ICI) has encouraged local governments to increase (rather than reduce) the number of building permits in order to broaden their tax base and compensate for the concomitant decrease in state transfers. In other words, the allocation of the property tax to municipalities in that case allows for the use of accommodative land planning as a variable for budgetary adjustment. Entrusting the same local authority with the power to both tax and regulate land tenure, which amounts to being able to define the tax base, can thus lead to an increase in new construction.

Zoning can have an effect on prices, but the manner of this is not clearly established. It is necessary to distinguish between the supply of land and the supply of buildings and, similarly, between artificial land and the number of buildings it generates. Theoretically, by constraining the supply of real estate, zoning policies have a negative effect on the number of new constructions, but land owners can anticipate regulatory change by subdividing their plots or negotiating with decision-makers.

The question of location is insufficiently studied: it is not a question of prohibiting the new constructions for which France has a real need, but of choosing locations carefully in order to contain sprawl, and to do so with neighbouring municipalities in consultation rather than competition.

Governance of land take and evolution of zoning

There is a trend towards grouping municipalities and coordinating their urbanisation around SCoTs, at the same time limiting the possibility, for those who would otherwise do so, of opening up natural areas to urbanisation or possible future urbanisation. However, a set of criteria related to distance, agglomerated population and various geographical considerations limits this regime. The ALUR law revamps the mechanism by giving it another philosophy: to avoid urban sprawl in municipalities not covered by a SCoT (where replaced by overseas territory development plans, the SDRIF, or the *Projet d'aménagement et de développement durable*, PADD, in Corsica).

14. In OECD countries, urban areas with more than 500,000 inhabitants are comprised of an average of 74 municipalities.

In the absence of an urban planning document, areas outside the currently urbanised parts of municipalities may not be opened to urbanisation in order to allow 'constructions and installations incompatible with nearby inhabited areas and the planned extension of existing constructions and installations', nor constructions or installations which the municipal council may approve in the interests of the municipality. Finally, in municipalities which are not covered by a SCoT, no authorisation for commercial development or for the operation of a cinema can be issued within an area or sector made constructible after the entry into force of the Urban Planning and Housing Act of 2 July 2003.

The dynamics of urban sprawl respond to two scenarios. In the first, zoning regimes are influenced in the medium term by the preferences of individuals, but in the long term, conversion to housing as well as price factors are the main determinants of urban sprawl. In the second scenario, however, if local governments manage urbanization by favouring public interest objectives rather than simply being re-elected, and thus free themselves from the pressure of owners and developers, then zoning will follow its own dynamics.

In rural areas, these changes mainly occur through the extension of zones, with a strong dependence on the existing secondary road network. Moreover, the scale of decentralization is crucial: at finer scales, the more it will allow local lobbies to influence zoning and the more it will generate competition between local governments to attract certain jobs and tax revenue. This phenomenon can be observed in peri-urban areas and in areas of agricultural decline. In response, several French laws (SRU 2000, Grenelle II 2010, ALUR 2014) have begun a movement towards recentralisation.

Avoiding land take in certain areas

Some types of areas are better protected than others, especially when they are used for production. The consideration of land characteristics in urban planning documents can allow ‘reasoned’ land take.

The protection of mountain and coastal areas

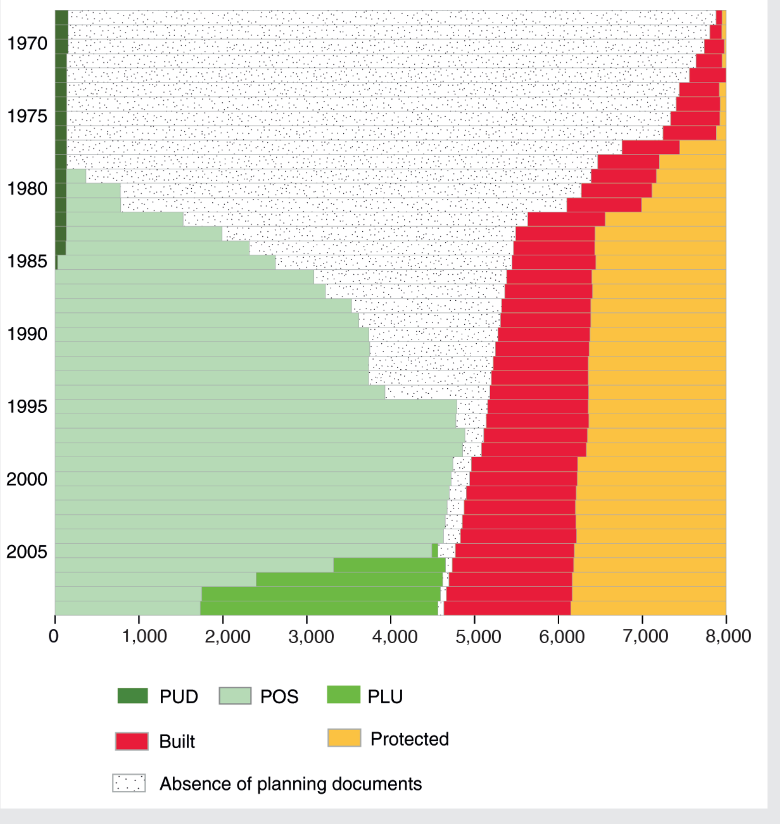
In addition to the special case of protected natural areas, urban planning law makes it possible to protect certain areas, including mountain areas and in particular ‘land necessary for the maintenance and development of agricultural, pastoral and forestry activities’ (C. urb., art. L. 122-9). Paradoxically, the protection of these activities authorises the consumption of agricultural areas, since 'the buildings necessary for these activities', but also sports facilities (skiing), in addition to 'the restoration or reconstruction of former alpine chalets or summer buildings', as well as limited extensions 'where the destination is linked to a seasonal professional activity', can still be authorised.

Developed nations, but also developing nations with particularly desirable coastlines, have adopted specific coastal legislation (Box 7.5). They are based on the implementation of similar principles: the delineation of non-buildable zones, construction perpendicular

Box 7.5. The example of Pays de Brest

The lure exerted by the coastline, in the absence of protective measures, diminishes significantly once regulations are introduced. Fig. 7.2 shows the change in the status of land parcels between 1968 and 2009: since the mid-1970s, residential construction has been increasingly restricted along the coast. The analysis shows that the regulatory measures have halved the risk of construction on parcels of land in the 100 m coastal strip. The proximity of infrastructure or pre-existing built-up areas now have a much more decisive influence on residential construction than does proximity to the sea.

Figure 7.2. Changes in the status of land parcels in Pays de Brest within the 100m coastal strip between 1968 and 2009.



to the coastline (at depth), and the protection of green corridors through the definition of outstanding areas.

Due to the environmental quality of certain coastal areas, traditional environmental law protections may apply to them. Examples include national parks (Port-Cros), nature reserves (Camargue) and marine nature parks (Côte d'Opale). In addition, since its creation in 1975, the *Conservatoire de l'espace littoral et des rivages lacustres* (CELRL) has been pursuing a land acquisition policy aimed at protecting the 'natural third' of the French coastline (in 2017, it will own 13% of it).

Regulation is not always effective

Urbanization around water bodies. The natural parts of the shores of natural or artificial water bodies with a surface area of less than one thousand hectares are protected over a distance of 300 m from the bank; all new constructions, installations and roads as well as all excavations and scouring are prohibited (L. 122-12 - for bodies of water of more than 1,000 ha, the Coastal law applies, the distance being then reduced to 100 m). However, the small size of a water body may justify the non-application of this measure. In addition, certain structures are allowed in these areas if linked to agro-sylvo-pastoral production or to activities at the site (gîtes, camping, reception and safety facilities, etc.) (L. 122-13). Other constructions and developments may be allowed by dispensation, depending on local circumstances.

Limited extension of urbanisation to areas close to the banks of inland water bodies are subject to the Littoral Act, and are justified and driven in the PLU, according to criteria linked to the configuration of the area or the acceptance of economic activities requiring immediate proximity to water.

The overseas territories are subject to the same laws as mainland France. Although these are adapted with regard to the competences of the relevant administration, their application may be difficult due to local, social and environmental circumstances. This is the case in Mayotte, where customary Muslim rights and common law coexist in land legislation, with sometimes contradictory rationales. The same is true in New Caledonia. More generally in the overseas territories, the regulatory principles of the 100-metre strip are superimposed on the 50 geometrical step (81.2 m) zone, which is subject to specific legislative and natural characteristics and particular socio-economic issues.

Coastal protection measures have been implemented too late (sometimes due to political and institutional weaknesses) in view of the rapid rate of coastal land take. Moreover, these tools often remain used to promote economic development rather than environmental protection. A review of the Coastal Law published in 2007 came up with mixed findings: while it did not question the legitimacy of a specific coastal policy, on the contrary, it pointed to shortcomings in its application and called for the renewal of certain provisions. Many conflicts exist around this issue between the different stakeholders and, ten years after this assessment, a reform document has been proposed, but has not yet appeared.

Climate change: the need to consider the increasing risks

Faced with repeated disasters, some territories are responding by adapting their urbanization patterns through more rigorous planning procedures aimed at the integration of these risks. When this is not the case, socioeconomic groups with the means to do so relocate to less risk-prone sites, thus triggering new land dynamics that tend to reinforce urban sprawl, as well as social inequalities. Indeed, when a population lacks the means to adapt and authorities are ineffective, reconstruction takes place on the exact sites of the disasters with little adaptation. In fact, these disasters are not 'natural', but result from the indiscriminate exposure of people and property to hazards. These effects could be reduced by the implementation of new management policies (Box 7.6). In their most pessimistic scenario, Neumann et al (2015) estimate that the population exposed to coastal hazards in low-lying coastal areas (1 in 100-year flood zone) could increase from 189 million in 2000 to 411 million by 2060.

Box 7.6. Towards an integrated coastal zone policy: Integrated Coastal Zone Management (ICZM)

Integrated Coastal Zone Management, or ICZM, is a public policy tool that the Council of Europe has been promoting since the 1970s. It was the subject of a European Union recommendation in 2002, but it must be acknowledged that its implementation is still ineffective. ICZM would, however, make it possible to deal with the sectoral regulations that apply to the coastline by taking an integrated approach to terrestrial and aquatic issues, and by placing resource use in the context of environmental protection objectives. In fact, although it aims to meet the principles of sustainable development, it is difficult to achieve this partly due to the profound divergence of interests between coastal users, but also because of the dispersion of institutional responsibilities (located at multiple territorial scales).

The partial protection of productive land

The law aspires to preserve land for agricultural use from a quantitative rather than a qualitative perspective, in other words, to preserve its availability. These measures can be considered effective, but weaknesses in their implementation and the exceptions provided for in the regulations limit their scope. The ways in which law and public policy can limit the artificialization of land are developed further below, while here the focus is on how the law preserves the availability of agricultural land. The rationale of more flexible zoning (which, in the case of the PACA region, covers an area five times as large, with an average of 43% of municipal areas) follows a stacking principle, the accumulation of which makes it possible to build a gradient of protection around iconic areas.

In the PLUs, areas within the municipality, whether equipped for agricultural use or not, can be classified as agricultural zones, 'to be protected because of the agronomic, biological or economic potential of the agricultural land'. Land use must therefore correspond to the intended function of the zone. This zoning also has an impact on the conditions for land rehabilitation following the operation of a classified facility. This protection also requires the involvement of agricultural and similar bodies when zoning is defined: the Chamber of Agriculture is consulted as part of the preparation of a SCoT or a PLU, and the Prefect may designate the *départementale de l'Équipement et de l'Agriculture* (Departmental Directorate of Equipment and Agriculture) as an associated public entity.

If the PLU and any amendments to it result in a reduction in agricultural or forestry land, approval of the PLU and any amendments may only be granted after consultation with the Chamber of Agriculture, the Regional Centre for Forest Ownership and, in areas with a registered designation of origin, the National Institute of Origin and Quality (INAO). However, this is only a simple consultation.

The absence of an enforceable town planning document does not leave the land without protection, since the rule of limited constructability prohibits building outside the currently urbanised parts of the municipality, with a few exceptions such as constructions and installations necessary for agricultural production and the development of natural resources. Moreover, the authority responsible for issuing the building permit may refuse the project or only accept it subject to special requirements if its location or purpose could compromise agricultural or forestry activities. This particularly applies as a result of the agronomic value of the soil or the existence of land delimited under a registered designation of origin or a protected geographical indication.

However, despite their number, these and other consultations provide only a weak defence against changes in land use. The protection of agricultural land must therefore be achieved through *ad hoc* mechanisms. This is the case for protected agricultural zones (ZAPs), which come under the jurisdiction of the Prefect. When a change in land use or occupancy that seriously alters the agronomic, biological or economic potential of such a zone is envisaged, advice from both the Chamber of Agriculture and the Departmental Agricultural Guidance Commission is required, and a justified decision by the Prefect is needed to authorise this change in the event of an unfavourable opinion from one of them (C. rur., art. L. 112-2). This regime thus makes it possible to go beyond a short-term economic horizon and counter any local pressure exerted on elected officials. The policy of protected agricultural zones is, however, very rarely applied.

The peri-urban agricultural area has benefited from special preservation measures since 2005 (*Loi relative au développement des territoires ruraux* - Law on the development of rural areas). Departments may define protective perimeters around peri-urban agricultural and natural areas (PEAN) with the agreement of the relevant municipality(ies) or public institutions responsible for the PLU, and after consulting the Chamber of Agriculture and following a public enquiry. The advantage of the system is that land within a defined perimeter cannot be included in an area that is or could be urbanised, nor in a constructible sector delimited by a municipal map, and that any modification of the perimeter resulting in the removal of one or more plots of land can only be made by decree. However, such protection remains fragile, as it depends on the goodwill of the Departmental Government, and has a somewhat vague scope, as the term 'peri-urban' does not clearly identify these areas. The urban areas as defined by INSEE can generally be used but, for certain Departments, this is a simplistic approach and does not encompass all areas under land pressure.

On its own, zoning as agricultural land does not prevent its artificialization, even when the zoning is justified by its agricultural use, and there is a growing trend towards artificialization. Thus, the share of agricultural land for which a building permit was obtained between 1980 and 2003 may represent between 55% and 71% of total non-residential construction (this is the case in the tip of Brittany, Normandy and part of the Massif Central, for example). In these regions, the rate of construction of new facilities is barely affected by changes in production aid (1984 milk quotas or the 1992 reform). The sharp reduction in the number of structures is in fact accompanied by a steady increase in livestock numbers, which requires the renewal of animal housing. 14,000 structures were built each year between 1980 and 1997. As a result of this restructuring, although the number of buildings is decreasing, the total area of built land in square metres is not, and reflects a strong correlation between agricultural restructuring (particularly in the dairy sector) and the artificialization of land for agricultural use (which is recorded by Teruti, but rarely by CLC – CORINE Land Cover). Moreover, greenhouses and farm buildings are counted as agricultural land by Teruti and CLC, whereas they most often involve land take.

The policies of local food and agriculture raise questions about the use of planning tools. The protection of peri-urban agriculture through freely used municipal planning tools would be more effective than PLUs, especially since they signal the strong commitment of local governance to an agri-urban agricultural development project, which then translates into a willingness to protect agricultural land. This involvement is a powerful legal tool for protecting peri-urban farms, provided that it integrates existing agriculture in the area into its multipurpose approach.

Finally, in a context of energy transition that sees the development of renewable energy production areas, jurisdictions are increasingly called upon to address the issue of the compatibility of ground-mounted photovoltaic power plants with the use of land for agricultural activity. In response to a need for clarification, a circular issued by the Ministry of the Environment on December 18, 2009, nevertheless stipulated that 'ground-mounted solar power plant projects are not intended to be installed in agricultural areas, particularly those that are cultivated or used for livestock. Therefore, the installation of a solar power plant on land located in an agricultural area is generally unsuitable given the need to maintain the agricultural use of the land concerned. However, the installation of ground-mounted solar installations may be considered on land which, although located in a classified agricultural zone, has not been used for agricultural purposes in recent times'. A probable, but moderate, degree of competition between these two uses remains to be studied.

Preserving agricultural land through fiscal tools

The tax reform measures mentioned above are aimed primarily at addressing the housing shortages in France, rather than directly improving control over the use of natural and agricultural areas. However, the achievement of the first objective may serve the second.

With the benefit of a more incentive-based tax system, the release onto the market of a greater number of building plots in urban or future urban areas can reduce land pressure in municipalities that are mainly covered by natural and agricultural areas. However, this positive link is only achievable if the relevant municipalities apply a rigorous policy of preserving natural and agricultural areas, and if these areas benefit from highly favourable taxation through the differentiation of rates based on land use (Committee for Ecological Taxation, 2013). It is feared that in municipalities on the margins of urban areas, a tax system on agricultural land based on the market value of land could accelerate applications for reclassification as buildable land because of the additional tax costs borne by farmers. In a context where local authorities could see the new tax system as a windfall in terms of public finances, perverse incentives favouring land take might then arise.

In France, the Law on the Modernisation of Agriculture and Fisheries (2010) introduced a tax on capital gains from the sale of unused agricultural land made constructible following a modification of urban planning documents. It aims to combat speculation on agricultural land, and thereby combat the disappearance of agricultural land, particularly as its proceeds are used to finance measures to help young farmers set up operations.

This tax is only automatically applicable to the first sale for profit of vacant land made constructible after 13 January 2010 through a PLU or a municipal map. This means that subsequent sales are not affected by this tax, and its effectiveness is therefore limited in the long term. In the United States, another form of taxation exists (Box 7.7).

Box 7.7. Agricultural land valuation in the United States

The U.S. government has authorized local governments to apply a use value to land, i.e. one that reflects the income derived from its current use. Theoretically, use value taxation can delay the conversion of agricultural land, and its effect is all the more important as the difference between potential market and use values is itself high. In other words, the moderating effect on land take will naturally be greatest in peripheral areas close to urban areas, where this difference is greatest, but modest in rural areas far from urban centres.

However, given the differences in land valuation between agricultural and residential uses near stressed urban areas, any tax incentive to maintain agriculture would be insufficient to change behaviour (IFS and Mirrlees, 2011). These elements do not suggest that any differentiated tax treatment of agricultural and natural land should be abandoned. They simply underline that tax incentives are of limited effect without a zoning policy or strict regulation by local authorities.

Densification: a strong will, and relatively positive effects

Since land take often proceeds incrementally, the approach to densification outlined in the SRU law has been extended by the ALUR law of 24 March 2014, which frees up urban space and density levels, provides a stronger legal framework for densification, and thus works in concert with tax incentives to densify. That being said, densification leads to impacts on biodiversity and human nuisances that must be taken into account in development policies. The threshold effects of urban density, as highlighted by studies focusing on species and assemblages of species, should be further integrated into proposals that focus on limiting urban sprawl. This policy of limiting urban sprawl, which has many advantages (limiting the loss of agricultural and forest land, reducing the carbon impact of cities by reducing travel), should be accompanied by specific measures to limit or compensate for the negative environmental effects (cf. chapters 2 and 3) of urban densification in the heart of cities arising from specific developments.

The impact of urban sprawl on local public spending and taxation

Urban sprawl makes infrastructure provision more expensive because economies of scale related to density disappear as the size of the city increases. The financing of these new urban developments is sometimes covered by transfers from the State or by exceptional income generated by the real estate cycle (building permits, construction taxes, revenues from the sale of public land, etc.). However, the problem of infrastructure funding generally affects the marginal or average taxpayer because urban sprawl promotes the arrival of new households that do not pay the full cost of their settlement. Numerous studies show that urban development thus leads to an inefficient allocation of local public investment.

Freeing-up of urban density and space through the ALUR law

The measurement of urban density has long been based on the Land Use Coefficient (COS), a measure that is easy to apply but which over-simplifies the measures of land occupancy. It is therefore necessary to look elsewhere for the required building capacity for a project, especially if the COS estimate is low and thus restricts the densification of the relevant land. The ALUR Law has therefore removed it (see Chapter 5). At the same time, the ALUR Law abolished the minimum surface area of buildable land in order to strengthen the supply of land within the city, and thus avoid urban sprawl on its outskirts. Finally, it also created a new coefficient that could limit the artificialization of urbanised areas (see below).

However, in principle, it does not remove all possibility of transferring building capacity, but gives it another configuration, and it is up to the municipalities to substitute the COS regime with other rules they define. By superseding the COS, the ALUR Act also modified the procedures for calculating the minimum density threshold used to calculate the sub-density charge.

The payment for sub-density was created by the amended Finance Law of 2010 with the aim of enabling municipalities and Public Establishments for Intermunicipal Cooperation (EPCIs) to combat urban sprawl. As such, the municipalities and institutions responsible for urban planning may set a minimum density threshold, below which a payment for under-density is due (C. urb., art. L. 331-36) and the proceeds of which benefit them. A PLU is necessary since this threshold is determined by zone within the municipality that are urban or are to be urbanised. The law has provided a framework for the definition of the threshold by municipalities in order to avoid tendencies to define the threshold for income generation rather than as a tool for controlling urban density. Below this threshold, developers must pay a charge based on the value of the land and the missing area to reach the threshold. While this mechanism creates an incentive to use space more economically, it remains optional, as the choice to implement it falls to individual municipalities or inter-municipalities. Making its implementation compulsory for all municipalities and inter-municipalities would provide an additional tool to raise awareness of the need to preserve land and to make developers more responsible.

Quantifiable targets

Activated by the Grenelle 2 law in order to combat land consumption, SCoTs and PLUs must include, in submitted reports, an analysis of the consumption of natural, agricultural and forest areas.

The ALUR law reinforces these provisions, and the submitted SCoT report must henceforth identify the capacity for densification and transformation of spaces, taking into account the quality of landscapes and architectural heritage. In addition, the PLU report must set out the provisions that favour the densification of these areas and the limitation of the consumption of natural, agricultural or forest areas, the changes in which must be analysed. With this in mind, the PLU's planning and sustainable development plan must set 'quantifiable' objectives for the moderation of space consumption and the fight against urban sprawl, in the same way as the SCoT's guidance and objectives document, with reference to the analysis of past land consumption.

Mechanisms to reduce the effects of land take

When land take cannot been avoided, for example to meet housing needs, or because the legal mechanisms have not led to the project being challenged, tools are available to reduce the impact of land take on the soil itself and on the environment more generally. The first of these tools is knowledge of the soils and the environment on which the transformation is planned. It is then supplemented by measures to recycle artificial land and limit the waterproofing of artificial surfaces.

Knowledge of soils prior to land take: a challenge for public policy

Environmental assessment: a tool to prevent land take that should be considered

Land use is not the main concern of the environmental impact assessment regimes applied to public or private projects (Directive 2011/92/EU), nor of the environmental impacts of plans and programmes (Directive 2001/42/EC). The latter Directive nevertheless requires an environmental assessment for urban and rural spatial planning or land use plans.

The translation into domestic law remains very limited, whether it is within an impact study or an environmental assessment:

• An impact study describes the elements likely to be significantly affected by the project, including land and soil. It also describes the significant impacts that the project is likely to have on the environment resulting, among other things, from the use of natural resources, in particular land, soil, water and biodiversity, taking into account, as far as possible, the availability and sustainability of these resources (C. env., art. R. 122-5).
• The environmental assessment of the planning documents includes a description of the likely significant effects of the implementation of the plan on the environment and, where applicable, on the soil, as well as the measures taken to avoid negative effects on the environment (C. approx., art. R. 122-20).

While soil is included, the approach is essentially surface-based. In-depth case law studies have found that no decision or plan has been overturned or annulled on the grounds that the impacts of a project on soil quality have not been sufficiently considered.

In addition, the scope of environmental assessment mechanisms does not cover a significant number of activities that ultimately result in land take, such as solar power generation facilities below 250 kilowatt-peak or indeed most building or development permits, due to high area thresholds above which an impact assessment is required.

Environmental assessment is a knowledge tool designed to prevent a plan, programme or project from adversely impacting the environment. However, knowledge of the soil is often neglected, which is detrimental in the long term, given the non-renewable nature of this resource at the human timescale. There is no doubt that a greater consideration of soil quality would considerably reduce the impacts of land take on the environment. This collective scientific report reveals a significant lack of knowledge of the baseline state of the environment and in particular of soils, which prevents any true measurement of the impact of land take. The obligation to measure and preserve this condition could be created through a law, and be modelled on a mechanism similar to that of preventive archaeology already in force. This would therefore be a form of preventive pedology.

Finally, the environmental assessment must in some cases include remediation measures. In terms of land take, the broadening of such a plan would therefore enforce the provision, at the time of the project's consideration, of measures to reduce artificialization. This important instrument would address the issues of reversibility and the objective of no net loss of biodiversity.

Land use and soil quality: a tool to be created?

Soil quality is rarely invoked as the factor cancelling the decision to classify land as buildable, unless there was an obvious error in the assessment: the legal land use classification is more often the result of a desired land use than the quality of the soil.

Reversing the trend would involve following the approach of the UQUALISOL-ZU project (Land use and soil quality in urban and peri-urban areas - application to the Provence Mining Basin) and its recommendations formulated within the framework of the GESSOL 3 programme. This would involve defining soil quality indices and integrating them into urban planning documents. These indices would allow the establishment of links to the possible uses of the soil, with the aim of allocating it as appropriately as possible to a particular use according to its qualities, and therefore not 'waste' it through artificialization that would have been more appropriate elsewhere (in terms of the indices). Moreover, it could create greater responsibility on the part of the municipalities and inter-municipalities, which would need to justify a land zoning decision that differed from that stated by the soil index.

There is growing interest in the classification of soils using composite indices. However, there is no consensus concerning, on the one hand, the measurement of their quality and, on the other hand, the most relevant and essential parameters for describing their characteristics and potential. Contamination regulations (exposure and health risk assessment for the population) do appear, however, to play a leading role in their characterisation.

Land recycling

One major challenge to reducing the impacts of land take lies in preventing the conversion of agricultural or natural parcels to an artificial state. In this context, land recycling is a key tool, but its implementation raises major public health issues. The conversion of former industrial sites is a challenge for the public authorities who must supervise the rehabilitation of polluted sites and soils. Some residual pollution may eventually become a source of nuisance. In this case, soil conservation can conflict with public health responsibilities.

French law is weak in this area, and the number of disputes attests to the uncertainty in which public authorities and project developers find themselves. This may form a barrier to the rehabilitation and recycling of land.

The size, shape and location of the plots are the main drivers of the presence of vacant space. Forethought is a key factor here and allows the identification of sites that are likely to form the basis of new transit networks and multifunctional green spaces. The assembly of vacant spaces ('hollow teeth') requires policies that provide incentives for owners to cooperate by granting higher densification capacities in the targeted spaces. Where appropriate, these policies would be complemented by the actions of public land authorities through the exercise of their right of purchase.

The literature exposes a need to renew tools and the financing of projects, but also control procedures. It may be possible to establish a reference standard for the quality of urbanised soils (see Chapter 2) that would be accompanied by an enforcement regime in order to control upstream pollutant inputs. Finally, continuing evaluation of restoration practices should be made systematic and automatic, and conform to a standardized protocol in order to accurately report on the effectiveness of the measures.

Limiting the sealing of artificialized areas

The sealing of surfaces makes it difficult, if not impossible, to reverse land take. However, in terms of biodiversity conservation and water management, tools exist to limit the use of sealing without necessarily jeopardizing the proposed use.

Nature protection in towns and cities

The law provides new instruments, such as the identification of ecological corridors in urban planning documents or the 'biotope coefficient'. Created through the ALUR law, the biotope coefficient applies at the municipal or inter-municipal level: the PLU can set rules imposing ‘a minimum allocation of non-waterproofed or eco-convertible surfaces, possibly weighted according to their characteristics, in order to contribute to the maintenance of biodiversity and nature in the city’. Established on the basis of a ratio between the surface area favourable to nature and the surface area of a built-up plot, this coefficient makes it possible to calculate the proportion of the surface area of a plot that is vegetated or performs other ecosystem functions. In Berlin, where the most extensive application to date has been conducted, this coefficient is helping to standardise and achieve the following environmental quality objectives: guaranteeing and improving the microclimate and air quality; developing and maintaining soil function and managing water resources; creating and enhancing habitat for fauna and flora; improving the human living environment. The coefficient is therefore applied to each surface type (for example: impermeable surface 0; non-planted permeable surface 0.3; permeable surface with scattered plants 0.5; vegetated surface on natural soil 1.0; vegetated walls 0.5, etc.).

This tool could also be useful in tempering the adverse effects of urban heat islands. Furthermore, the impacts of structures on biodiversity could be better understood, and their incorporation into the tool would require only minor changes to the existing legal framework. For example, in terms of urban planning, the building code could pay greater attention to biodiversity by encouraging greater heterogeneity of building heights and vegetation strata, which would favour bird abundance in a dense city.

Water management and limiting the sealing of surfaces

Soil restoration is now of significant interest, with progress illustrated, for example, by the Biodiversity law of August 2016 which requires new car parks to be permeable. In the same vein, water management at the local scale, as at the watershed scale, is subject to measures to limit ground sealing, whether to meet the objective of flood regulation or to reduce runoff and associated pollutants. Thus, the Water Act of 3 January 1992 instituted Article L. 2224-10 of the General Local Authorities Code, which requires mayors to delineate areas for municipal and non-municipal sanitation, along with ‘areas where measures must be taken to limit soil sealing and control the flow of stormwater and surface runoff’. This provision introduced ‘rainwater zoning’, reinforced by law on 30 December 2006, which imposed a general obligation of ‘collection or treatment at the expense of local authorities’.

These measures result in the creation of permeable surfaces, but they should be accompanied by work to increase the absorption capacity of the soil (to achieve a result of approximately 1 cm/s).

Mechanisms to compensate for the effects of land take

Currently, in France there are no offset mechanisms specifically intended to compensate for land take and/or its most significant impacts (on biodiversity, but also on hydrology, soil pollution or urban climate). However, there are three mechanisms that may be applicable: compensation as provided for in impact studies, compensation as provided for in the Forestry Code and, finally, the collective agricultural compensation mechanism.

Compensation as provided for in impact studies

The laws discussed above touch upon compensation for environmental damage in general, and to soil in particular. Compensation is a 'sweeping measure' which only occurs at the end of a hierarchical sequence, after it has proved impossible to avoid or reduce land take. The question is rarely addressed in urban planning law, if at all, although it is more commonly applied for works and developments such as transport infrastructure projects. Compensation is concerned with the naturalness of the soil, since it is a matter of 'compensating, while respecting their ecological equivalence, for the expected or foreseeable damage to biodiversity caused by the carrying out of works, a construction project or other activities, or the implementation of a plan, scheme, programme or other planning document'.

However, the assessment of the adequacy of the response is speculative in nature, since it anticipates the results of the implementation of the measures. A remedy has been found, with an obligation for the project owner to monitor the implementation of these measures and their effects on the environment. In the case of land take, the measure could consist, for example, of rehabilitating an artificialized area by restoring its natural functions, or in the preservation of environments that compensate for ecosystem services affected by such land take.

Forest compensation

The Forest Code makes forest clearing operations subject to the condition that other afforestation or reforestation works be carried out on an area of similar size to the cleared area including, where appropriate, a multiplying factor between 1 and 5 based on the economic, ecological and social values of the timber and forests subject to clearing, or other silvicultural improvement works of an equivalent value.

This mechanism thus preserves forest availability by taking into account the characteristics of the cleared timber. That being said, recent amendments (2014) have resulted in the creation of a strategic forest and timber fund, which enables the petitioner to fulfil his obligation by paying an equivalent amount.

Collective agricultural compensation

The Law on the Future of Agriculture, Food and Forestry (2014) requires that a preliminary study be carried out for the project owner of public or private works, projects or schemes likely to have significant negative consequences on the agricultural economy. This study comes under the heading of ‘collective agricultural compensation’.

This mechanism is interesting from the perspective of land take, but its scope is limited. The Rural Code provides for three cumulative criteria for projects to be subject to this requirement for compensation:

- Projects must be subjected to a ‘systematic’ impact study and not ‘on a case-by-case basis’, i.e. not depending on surface or volume requirements.
- These projects must also be located on plots of land that are or have been designated for agricultural activity within the last five or three years, as defined in the urban planning documents.
- The projects must involve the permanent removal of an area, as a rule greater than 5 hectares.

This instrument is still too new for a full assessment to be made regarding its effects. Furthermore, it is important to note that compensatory measures are not necessarily expressed in land terms.

Compensation for land take: future prospects?

Germany is regularly cited as an example of a country that has set up a compensation mechanism for land take. Urbanisation has, in fact, been compensated for since the end of the 1990s by means of an ecopoint market, which is managed by agencies at the *Länder* (state) level. For example, in the city of Dresden, measures for 'soil unsealing' compensation have been explicitly provided for, and between 2000 and 2008, an average of 4 hectares of land was unsealed.

Monetary compensation is also under consideration, and the Czech Republic and Slovakia are examples of countries that have created an agricultural land classification according to its fertility. Where a project involves the conversion of high-quality land, the developer must apply for a special permit issued either by the Region or by the Ministry of the Environment and pay a sum corresponding to the price per square metre multiplied by the artificial surface. However, this mechanism is considered very lenient in view of the charges, especially in areas of high land pressure.

A current French example is the transfer of building rights (Chapter 5). To recap, the transfer of building rights is an economic tool that can influence the nature of land and real estate markets. It allows the project developer to increase the density on one plot by purchasing unused rights over another plot in the same area. At present, this tool is barely used, due to the lack of a sufficient market to set consistent prices, the legislative constraints, and the prior approval regime in place. However, it could possibly be developed under the auspices of the ALUR law (2014) which created a mechanism for the transfer of constructability in areas to be protected on the basis their landscapes.

Conclusions

Avoiding, reducing or compensating for land take, and in particular its most impacting and least reversible forms such as the sealing of surfaces, are three objectives whose success requires the integration of various legal and fiscal tools which have not necessarily been designed for these purposes.

Three elements stand out from this review of French law:
- Legal issues arise over the concept of land take, which is not defined by law and which is a concept that is not found in European or international legislation.
- As a result, there is no general policy to combat land take. Public authorities at the national level have a limited approach by focusing, for example, on the fight against the fragmentation of agricultural land. The effectiveness of measures is thus reduced, especially since their application is rarely binding.
- More widely, the absence of specific regulation of land take is in keeping with the French situation, where soils are not directly included in a protection framework.

The legal literature on land take is thin, and it is rare for an article to be devoted exclusively to this question except when legislation or a judicial decision concerns it (such as the specific provisions of the ALUR law). Land take, under this title or under terms that imply it (urban sprawl etc.), is more often addressed incidentally, in the form of a provision.

A definition of land take, or criteria to characterise it, would allow a clearer legal understanding of it, even if the absence of such a definition does not preclude the use of legal instruments to limit or avoid it.

The definition of a national policy for the protection of soil against artificialization (land take), along with a statement of general principles, would soil to be promoted as a 'national cause' (the protection of soil against its artificialization is an objective of general interest). It would also raise awareness of soil protection and, last but not least, provide a basis for the adoption of legal provisions capable of satisfying this goal.

Taxation is not neutral with regard to land take. It is generally seen, particularly in France, as the main weapon in the fight against housing shortages. By using non-constructed land in urban areas in particular, future developments may well serve the objective of less land take. It is clear, however, that any tax reform based on the adjustment of rates and/or the creation of new taxes will only be fully effective if accompanied by a convergent land regulation policy firmly based on planning tools. As such, the question of the level of government to which to entrust this policy arises. Because the issues and areas concerned often range beyond the boundaries of municipalities, the growing importance of inter-municipal cooperation with regard to this subject should be encouraged.

Despite the political impetus toward ecological transition (2013), little work has been undertaken with regard to financial and fiscal instruments that could encourage densification, not so much because of the technical nature of the exercise but because of the lack of specialists in these matters. The bulk of the issue has been addressed in the framework of the French Committee for Ecological Taxation (now the Committee for the

Green Economy). Other suggestions that should be explored have been made by this Committee. These include the taxation of vacant offices along the same lines as the taxation of vacant housing, which would encourage owners to place them on the market and thus reduce new office construction. This might also be expanded to the taxation of industrial and commercial wasteland in order to encourage land recycling.

With a few exceptions, current taxation has not been conceived in terms of incentives to limit land 'consumption', but in terms of financing infrastructure or other policies. It therefore, by its nature, only has an indirect effect on reducing surface sealing when it is not actually neutral or indeed encouraging land consumption. If land-related taxation is to be used as a means of limiting urban sprawl and land take, some guidelines should be observed:

- The 'release' of land in order to encourage densification and avoid urban sprawl should not prohibit construction in certain 'appropriate' areas.
- The income from taxation introduced to constrain the use of land must not benefit the authority establishing it, its purpose being deterrence and not the generation of revenue.
- The tax rate must be incentivizing.
- The constitutional principle of financial autonomy of local and regional authorities (their own revenues must constitute a decisive part of their total resources) must be respected.

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Soil artificialization is a recent concept, initially responding to the concern to quantify the loss of land available for agricultural use through changes in land use. Today, it refers to the overall reduction in the proportion of land devoted to agricultural and forestry activities or to natural areas, thus going beyond the strictly agricultural dimension.

Land artificialization and land that has already been 'artificialized', have become, particularly in France, a major issue of public debate and political concerns. Land artificialization is thus seen as one of the main factors in the erosion of biodiversity, which explains why, since 2015, the rate of land artificialization is one of the 10 'Wealth Indicators' developed by the Government to monitor its public policies.

In this context, the French Ministry of Ecology, the French Agency for Ecological Transition (ADEME) and the French Ministry of Agriculture, Agrifood, and Forestry wanted to have access to scientific knowledge that would enable them to better identify the economic and social determinants of soil artificialization, its impacts on the environment and on agriculture, and the levers for action likely to limit its development and negative effects. They entrusted IFSTTAR (now université Gustave Eiffel) and INRA (now INRAE) with the task of carrying out this collective scientific expertise. The main conclusions are presented in this book first published in French in 2019.

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