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

CONDENSED REPORT OF THE COLLECTIVE SCIENTIFIC ASSESSMENT - DECEMBER 2017

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IFSTTAR

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This document summarizes the collective scientific assessment report jointly requested by the Ministry in charge of the Environment (General Commissariat for Sustainable Development, CGDD, Ministry of Ecological and Inclusive Transition, MTES), ADEME (Environment and Energy Management Agency) and the Ministry of Agriculture and Food (Directorate General of Economic and Environmental Performance of Enterprises, DGPE), Conventions No. 15-MBGD-GESSOL-1cvs001, No. 14-60-C0067, No. 154-14-13.

Cover photo: Peri-urban area of the agglomeration of Chalon-sur-Saône – Credit : Christian Slagmulder - Inra

Délégation à l'Expertise, à la Prospective
et aux Etudes (DEPE)

Artificialized land and land take; drivers, impacts and potential responses

Synthesis of the collective scientific expert report

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December 2017

List of acronyms

ALUR: Law on Access to Housing and Renovated Town Planning

CLA: Atmospheric boundary layer

CLC: Corine Land Cover

CLU: Urban boundary layer

ETM: Metalloid and trace elements

GIZC: Integrated coastal zone management

HAP: Polycyclic aromatic hydrocarbons

JRC: Joint research centre

ICU: Urban heat island

INAO: Institut national de l'origine et de la qualité (National Institute of Origin and Quality)

MAJIC: Update of cadastral information

MES: Suspended matter (solids)

MOS: Land use

PEAN: Protective perimeters around peri-urban, agricultural and natural spaces

PLU/PLUI: Local urban plan / Intermunicipal urban plan)

RPF: French soil classification system

RUTP: Urban wet weather discharges

SAFER: Land Development and Rural Settlement Society

SAU: Agricultural area

SCOT: Territorial coherence scheme

SDRIF: Master plan of the Île de France region

SGEU: Urban water management system

SRU: Urban Solidarity and Renewal Law

SUITMA: Soils of urban industrial traffic and military areas

THR: Very high spatial resolution

UGB: Urban growth boundary

IUCN: International Union for Conservation of Nature

ZAU: Zoning in urban areas

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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 have requested** a Collective Scientific report (ESCo) through an **IFSTTAR** and **INRA review 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 countries.
- Beyond these measurements, the question of the determinants of land take and of their possible hierarchy is central to understand the evolution of this land-use change and to identify the land take trends taking shape.
- Considering these challenges, it is necessary to better identify the impacts of the phenomenon both on the biotic and abiotic environment and on the living conditions of populations, and the economic and social dynamics with a specific focus on the agricultural impacts.
- Lastly, policy tools to control land take and to limit the negative impacts require particular examination as they are numerous, and may be convergent or divergent between each other or with other public policy instruments.

To answer these questions, IFSTTAR and INRA applied the classic principles of an ESCo scheme (see Box) which is based on international scientific references relating to the various aspects of the questions. As a result, certain phenomena, in particular recent ones, cannot be precisely investigated, either because of the lack of published works, 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') 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 uncertainty from the different scientific disciplines mobilized for this review revealed that the concepts of urbanization ('urbanization') or 'sealing' were preferentially used. 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.) were recruited for the ESCo 'Land Take' project. Some have coordinated specific aspects of the review and participated in the integration of different perspectives and disciplines, while others contributed specifically to the chapter(s) relating to their particular specialty. Given the multidisciplinary nature of the issue of land take, the expertise of the experts is varied: they come from economics, geography, ecology, pedology, hydrology, agronomy, law, etc. (The list of all contributors and their scientific specialties are available at the end of this document).

The results of the expertise 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 (see Appendix). 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.

The Expert scientific report (ESCo), principles and methods

This ESCo, jointly conducted by IFSTTAR and INRA, was conducted according to the principles of collective scientific reports and the approach implemented by the Delegation for Expertise, Foresight and Studies (DEPE) of INRA.

Scientific expertise in support of public policies

The expert mission in support of public research into public policies was reaffirmed by the Research Orientation Act (2006). The provision of scientific arguments in support of political positions is now a necessity in international negotiations. However, the body of scientific knowledge is increasingly large, and produced in a wide variety of fields that are difficult for decision-makers and stakeholders to access. The role of an ESCo is defined as the critical examination and assembly of knowledge available in very diverse fields of knowledge and relevant to inform public action.

The Charter of scientific expertise

This activity is governed by the National Charter of Expertise of 2011, which sets out principles for conducting such an exercise, and which ensures the robustness of its conclusions and recommendations. This charter sets out four main principles:

- Competence is at the level of the organizations, which only engage expertise in their field of competence, and at the level of experts who are qualified on the basis of their scientific publications;
- Plurality is understood both from a multidisciplinary point of view by systematically associating life sciences and human and social sciences, and from a disciplinary point of view in order to promote the expression of disagreement as critical exercise for the pursuit of knowledge. It is also evident in the diversity of the institutional origins of the experts.
- Impartiality is guaranteed by the knowledge of the possible links of the experts with socio-economic actors (mentioned in a declaration of interests filled by each expert), and by the diversity of the expert contributors;
- Finally, transparency is reflected in the production of analytical and summary documents made available to all.

Definition and operation of ESCo

The ESCo establishes an inventory of academic scientific knowledge from which elements are extracted and assembled to answer the questions asked by the sponsors. The questions addressed to INRA and IFSTTAR were set out in specifications that are the result of collaboration between the sponsors and the research organizations, setting the limits and the content of the expertise. A monitoring committee, gathered around the sponsors, acts as an interface between the experts and the sponsors and oversees the progress of the work. An advisory committee of stakeholders, bringing together a wide range of stakeholder representatives, allows the issues raised by each stakeholder to be expressed, and provides a forum for discussing the initial results of the work.

The experts, gathered in a team led by one or more scientific leaders, each write a contribution indicating the bibliographic references used. All of the contributions together form the expert report that is posted on the research organizations' websites. Leaders and experts are responsible for the report. A synthesis and a summary for the sponsors and the public debate are extracted.

The research organizations, Ifsttar and Inra, commit themselves to the conditions under which the expertise process takes place: quality of the documentary work, updating of the bibliographic sources, transparency of discussions between the experts, facilitation of the working group and drafting of syntheses and communication documents in a form that combines scientific rigor and readability by a wider audience.

Introduction: 'Land Take', an ambiguous scientific concept

A concept whose statistical measurement remains uncertain …

The concepts of 'artificialized land' and 'land take' 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[1]. The approach was intended to support the theory that changes in agriculture 'have shaped the rural landscape'[2] and to investigate the causes of agricultural land loss. 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, 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', applied to non-agricultural, non-forest and non-natural uses of soils, has flourished in public debates and political discourses. 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. It has been, since 2015, one of the Government's 10 'new wealth indicators'[3], based on the work of the 'Stiglitz' Commission [4], and appears 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'[5]. This concern is reflected in the recent directive from the Prime Minister to his environment minister, Nicolas Hulot, to propose strategies 'before mid-2018 to fight against land take and the depletion of soils, one of the main threats to biodiversity'.

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 underlie 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.

[1] Slak M.-F., Vidal C. (1995). 'Ter-Uti, indicateur de paysage', *Agreste*, cahiers n°21.
[2] Slak M.-F., Vidal C. (1995). 'Les mutations de l'agriculture ont façonné le paysage rural', *Agreste*, cahiers n°21, pp. 47-56.
[3] Service d'information du Gouvernement (2015). *Les nouveaux indicateurs de richesse*. Paris : Service du Premier ministre, 74 p.
[4] Stiglitz J., Sen A., Fitoussi J.-P., coord. (2009). *Rapport de la Commission sur la mesure des performances économiques et du progrès social*. Rapport au Président de la République, Paris : La documentation française, 324 p.
[5] Ducos G., Barreau B. (2014). *Quels indicateurs pour mesurer la qualité de la croissance ?*, Note d'analyse, Paris : Fr. Stratégie, 12 p.

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 of material, inputs of exogenous materials (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 changes, associated with the particular activities that develop on these soils (classified in 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 which will be examined in detail later, more than 30% of artificial soils in 2014 were 'artificial grassy soils'. These substantial areas (1.6Mha) 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.)..

The linchpin of the degree of ground sealing or, more generally, the level of disturbance to the ground, 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 source, 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, the source identifies that as of 2012, 75% of artificialized soils are located within continuous or discontinuous 'urban fabric' (2.3 M² ha), the rest being industrial or commercial areas, road networks, railways, material extraction, 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 inhabitants live in an 'urban unit' (Figure 1, Box), a rate comparable to that of other industrialized countries. In some European countries such as Belgium or Denmark, this rate approaches 90%. No developed country today can avoid urbanization, regardless of their political or economic regimes, 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 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.

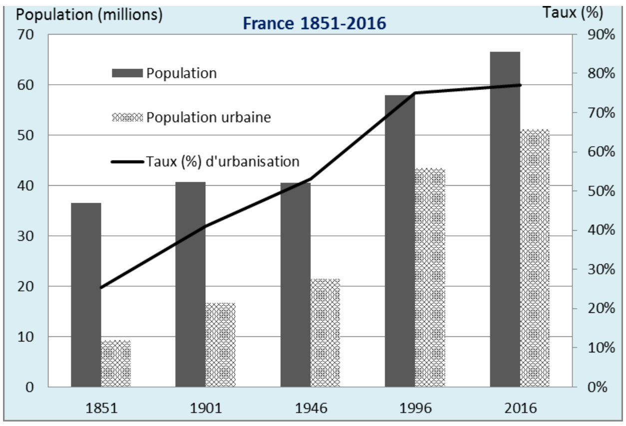

Figure 1. Population, urban population and urbanization rates
Source: Insee

Nevertheless, the agglomeration of populations and economic activities in a small number of locations creates a trade-off, in 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, increasing their land use 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. The order of magnitude of these average densities is thus about 2,000 inhabitants per km^2 for the cities of North America, 10,000 to 40,000 inhabitants/km^2 for the Asian cities, and 4,000 inhabitants/km^2 for European cities.

Urban sprawl, a corollary of metropolisation

Urban sprawl occurs according to two contradictory processes depending on the geographical scale of observation. At the national or continental level, metropolisation 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 resulting 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 (Figure 2). It is this double phenomenon of urban sprawl that, in France, led INSEE to develop its Zoning in urban areas (ZAU) in addition to its urban units-rural municipalities distinction (see Box). In a second step, the extension of the metropolisation movement can also induce an extension of urban sprawl areas around secondary peripheral centres that were formerly 'autonomous' (Figure 2).

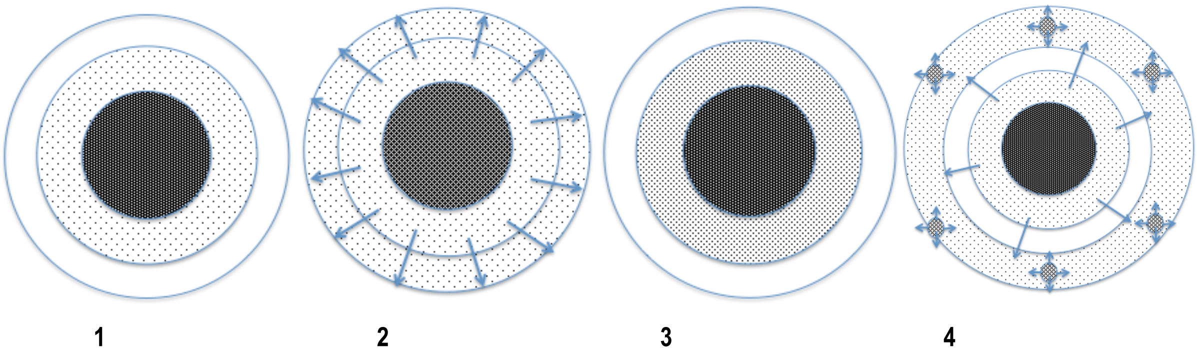

Figure 2. Illustration of the phenomenon of 'Leapfrog', literally 'to exceed' in French, which schematizes the forms of urban sprawl. Grey scales, from darkest to lightest, correspond to the density of the population, from the highest to the lowest.
1: Pre-growth; 2: Growth by urban extension; 3: Growth by densification of the periphery;
4: Growth by expansion of secondary towns (© Gilli, 2017)

Box: Urban units; Urban centres (poles urbains) and their surrounding 'crowns' as seen by l'INSEE

Since 1954, INSEE has, through its goal of distinguishing between urban and rural areas, utilised the concept of urban unity that combines the continuity of buildings and the number of agglomerated inhabitants. An urban unit is then defined as a municipality or a group of municipalities that has a continuous building area (no break of more than 200 meters between two buildings) and which has at least 2,000 inhabitants. Every commune encompassing an urban unit is itself are considered urban, with others considered rural communes.

At the beginning of the 1990s, it became necessary, in order to account for the geographical consequences of urban sprawl, to complete this urban-rural dichotomy by a 'Zoning in Urban Areas' (ZAU). It has already been the subject of two versions (1996 and 2010).

In the 2010 version, the **Urban Centres (Pôles urbains)** are made up of the subset of urban units that offer at least 10,000 jobs (and which are not located in the crown of another urban center). **Medium Centres (Moyens pôles)**, urban units of 5,000 to 10,000 jobs, and **Small Centres (Petits pôles)**, urban units of 1,500 to less than 5,000 jobs are also identified.

Around these centres, **crowns** or areas of influence of these centres have been identified. These are all rural municipalities or urban units (all in one block and without enclaves), where at least 40% of the employed resident population works in the centre or in municipalities attracted by it.

The areas, each containing a centre and its crown, are divided into three categories: '**Large urban areas**', which include urban centres and their peri-urban crowns, the '**medium areas**', around the medium-sized poles, and the '**small areas**', around the small poles.

Finally, among the municipalities not included in the areas, some send at least 40% of their resident assets to work within a number of areas, without reaching this threshold in any particular one. Within these communes, called multipolarised, we distinguish **multipolarised communes of large urban areas**, of which at least 40% of resident assets work in several large urban areas, and **other multipolarised municipalities**.

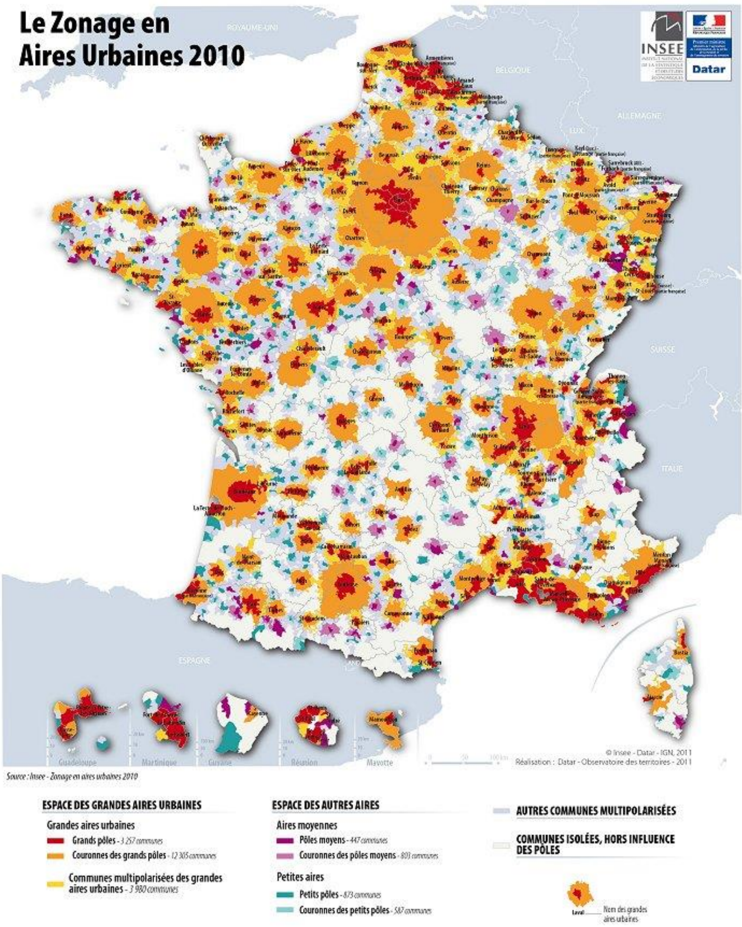

Figure 3. Urban zones according to INSEE, 2010.

The first form of urban sprawl thus increases the surface area of the city and extends its borders: the artificialization of the soil 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 soil is closely linked to the urbanisation process but takes place in communes outside the city, seen as a place of built-up continuity.

This process of urban sprawl by periurbanisation 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. In about thirty years, between the early 1970 and the end of the twentieth century, it transformed the demographic balances between urban and peri-urban areas and French landscapes, especially peri-urban. 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 hosts 95% of the metropolitan population (Figure 3). While nearly 50 million French people live today in a centre, almost 22 million live in a peri-urban commune, most often under the influence of one (or more) of the 241 large urban centres[6]. 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 increases to 72 inhabitants/km² in the crowns of these same centres, probably leading to different issues regarding the land take that unfolds there.

Initially for 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 infrastructures (rail and road) has developed between cities and within their areas, aimed both at improving access to peri-urban areas and at improving interurban links. The resulting land take thus also affects more distant rural areas (i.e. not peri-urban), and then associates other types of land take, linked to the development of tourist and leisure activities, second homes linked to them, and industrial and commercial enterprises which find certain advantages there.

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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 notion. Its components are multiple and complex; consequently, so will the analysis of its causes and consequences. To try to understand this clearly, it seems necessary to have an analytical framework that can serve as a basis for interpreting scientific results or reposition them in the specific context(s) of France. From the above analysis, it emerges that the causes and consequences of land take, 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.), to which it should be associated with the way in which it is combined with artificialized soils of different coverage, that is to say, the landscape mosaic in which it fits ;
- Its **positioning in the urban fabric** (centres of dense cities, suburbs, zones extending the city's borders, peri-urban municipalities, municipalities outside urban influences);
- The type of **activities that take place** there (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 read, knowing that, in order to evaluate the impacts of the change of land use towards artificialization, it is necessary to take into account also has characteristics of the soil before its artificialization.

In order to take more directly into account the terms in which the debate on land take is currently taking place, this synthesis has opted for a structure more directly linked to the issues at stake. After a critical examination of the **methods of measurement** of land take and the **results** obtained in the French case (**Chapter 1**), the first focus is on the **environmental impacts of the land take**, while trying to **limit ourselves to the most direct effects** of land take on the environment. Since artificialized land supports all economic, 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. A first focus is on the **very direct effects** of artificialization **on the soils themselves**, from the point of view of their physicochemical properties and from the point of view of soil biology (**Chapter 2**). The focus is then extended 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 on the urban climate, on air and noise pollution in this environment (**Chapter 3**). Taking these few indirect effects into account, included in ESCo's specifications, can be seen

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[6] Brutel C., Levy D. (2011). Le nouveau zonage en aires urbaines de 2010. *Insee Première*, 1374 : 1-4.

here as an exploration of 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 is paid to the **direct and specific effects of land take on the agricultural sector and activity**, especially in the urban fringes and peri-urban areas: loss of agricultural land, reduction of productive capacities, land pressure and environmental conditions for agricultural activity (**Chapter 4**). The economic and social determinants and impacts of land take are only examined in the second part, and are organized around **household residential location strategies** and the resulting **demand for housing construction** (**Chapter 5**), then 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**). The **artificialization of the coastline**, which concentrates and crystallizes the manifestations and determinants observed at the national level, calls for special consideration (**Chapter 7**). Finally, the **responses that public policies can make** to land take are discussed (**Chapter 8**).

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

Given the differences between French sources on artificial surfaces and their recent changes, it is necessary, firstly, to review the approaches and methods that allow this type of measure and the way in which they are employed as public statistics, to understand the uncertainties and limitations (1.1). 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 evolution of land take in France while placing these trends in a European context (1.2). Despite the differences in the assessment of the rate of land take, all sources converge to conclude that there is a trend towards increased land take both in France and in Europe.

1.1. Objectives and methods for measuring land use and land-use change

None of the methods that make it possible to identify artificialized land and to understand land take is 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 categorization of land uses that land take will be identified, as a category of a typology of uses, itself composed of possible subcategories. It is on these methods of land use analysis and on their capacity to identify artificialized land that we focus on here, after having specified the factors which more particularly concern land take

1.1.1. 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 patch. The measurement of land take refers to three things: surfaces, the urban footprint and the change of state.

- **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 that some so-called non-artificial zones are impermeable and that so-called artificial zones are perfectly 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 at 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 task does not describe the totality of the land take since it focuses on the urbanized space, and omits, for example, the numerous transport infrastructures that connect the urban areas.

- **Land use change, artificialization**

Artificialization considers the modification of initial surfaces in artificialized spaces (transformed for a non-agricultural use) over a given time step. Several elements can be observed: the location, the type and pace of these changes. According to the scientific literature, relatively few examples are based on 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 opening of free archive images has created an enthusiasm for time series studies.

1.1.2. Methods and data for measuring land-use change and land take

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 for the production of data on a European and global scale, but remote sensing methods are not dedicated towards measuring the extent of land take. On the other hand, they 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, aggregated statistics).

Despite a 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 to extrapolate information.

1.1.2.1. Remote sensing methods: diversity, benefits and limitations

- **Remote sensing data**

Most of the work on the measurement of urbanization, soil sealing or land-use change by remote sensing has been done using Landsat image series (MSS, TM, ETM +, OLI). There is no single product to measure land take, and the choice depends on the adequacy of the specificities of the available images (spatial, temporal, radiometric and spectral resolutions, temporal depth, etc.) to the desired objectives (characterization of type of surface or urban footprint, evaluation of dynamics). Research using remote sensing and 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 (THR) sensors, and multi-source and multi-image image fusion methods between different resolutions. Radars are useful to detect the land in cloudy zones (essential for example near the equator or the poles). 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 of the data collected 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. The active remote sensing technology LIDAR can thus be used as a means of estimating the height of buildings with the aim of detecting three-dimensional changes and estimating urban densification.

- **Methods of processing satellite images**

Classification methods. Classification allows the classification of pixels into classes according to a nomenclature. Classification is often multi-spectral and some methods are 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. It can be vegetation, brightness, building, soil moisture, morphological or landscape cues, etc. Other spatial data such as digital elevation models, geographical reference data, or aerial photography is often used to enhance or validate results locally.

Object oriented methods. Since the 2000s, the scientific community have moved towards classification methods where the units to be classified are not simply pixels of 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 THR 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. The current trend is to develop hybrid methods that combine both pixel and object methods.

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 the infrared (indices of vegetation, brightness, building, 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 the images, studies seek to characterise and quantify the spatial organisation of the built environment and their spatio-temporal evolutions (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 understand 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 then the interpretation is done. Image processing tools are often used to help define the outline of the areas. The classic case is the production of the CLC database, which is central to measurement 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 European Earth observation program Copernicus. In France the SOeS department of the Ministry of Ecological Transition is responsible for its implementation. This vector base, 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.

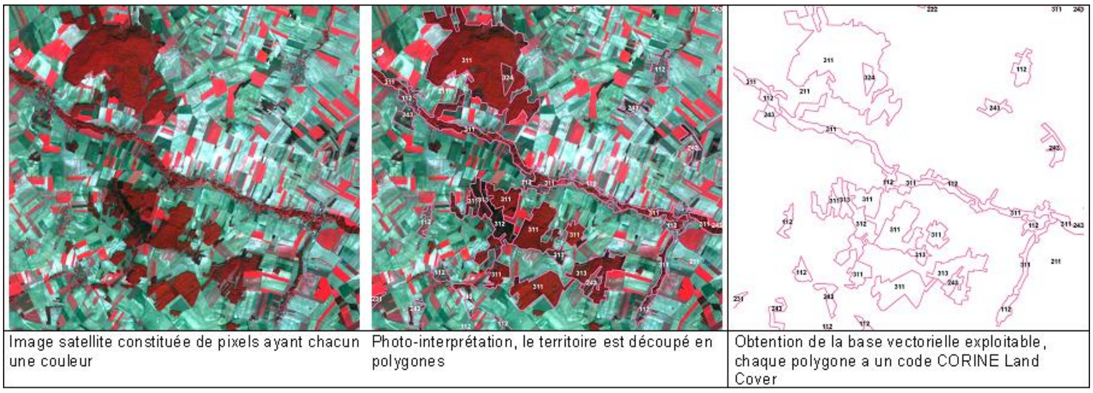


Figure 1-1. Schematic diagram of image interpretation

CLC favours the biophysical occupation (cover) of the land to its use, by classifying the nature of 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: Urbanized Areas (Continuous Urban Fabric and Discontinuous Urban Fabric), 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), Non-agricultural artificial green spaces (urban green spaces, sports and leisure facilities). The CLC data therefore aims for a detailed understanding of land take.

The complete database divides the territory into polygons of more than 25 hectares, each with a nomenclature code and the change database maps 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 it uses are high, which, in spite of their regular improvement, limits the spatial precision, in particular in sparsely-populated areas.

1.1.2.2. Field statistical surveys

Statistical surveys are based on direct field observation of land cover over a defined number of observation plots and thus require the definition of samples on which these precise surveys are made (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 can be questioned in terms of the distribution of points, their number and their 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[7].

1.1.2.3. The value-adding to administrative files and databases

Land files are directly derived from the fiscal cadastre covering the national territory. The Cerema, which formats and disseminates them on behalf of the Ministry in charge of the environment, has implemented a method to determine the annual evolution 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 the SAFER (Land Development Company of Rural Settlement) 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 allows an almost complete coverage of the contours of parcels and the built polygons (Data from the Informal Cadastral Plans (PCI) and BDPARCELLAIRE © of the IGN). These data are available annually and gradually cover the territory. Most of the geomatics services of local authorities that are interested in the measurement of urban sprawl, had the practice of improving the layers resulting from standard CLC satellite data, by using these data to better evaluate and qualify the consumption of space for urbanization[8] and supplementing them with IGN BDTopo data to map infrastructure. This data can be linked to the State Land Files (MAJIC files[9]) which contain very detailed information on the owners of land and property, as well as on the characteristics of built properties and parcels. Today, they can use Cerema's cadastral files when they do not have MOS (Land Cover mode).

The possibility of relying on several temporal versions of the PCI makes it possible to reach an error rate lower than 0.01% (Urbansimul project[10]). 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 the owners who are central drivers of the dynamics of land take. They also distinguish between hard and lightweight construction, which can be very useful for assessing the reversibility of buildings. Other recent vector sources, urban planning documents in the format CNIG/COVADIS 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 evolved very quickly (in PACA in 2017, more than 50% of municipalities were covered).

The combined use of such vector data makes it possible to analyse the process of land take at the level of the spatial unit at which decisions are made (the parcel or group of parcels) while including the main descriptors of the properties and owners, and allowing analysis of interactions with zoning plans that are intended to regulate the phenomenon as well as the land and real estate market.

1.1.2.4. Approaches by retrospective or predictive modelling

The predictive modelling of land take is a recent and rapidly expanding 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. Most studies use historical land cover data to calibrate and validate these 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. More than 80% of studies use models based on the 'individual centered' approach from cellular automata (SLEUTH, CA-Markov, Land Change Modeler, CLUE, MOLAND, etc.) although a significant number opt for 'multi-agent' models. 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

[7] For an analysis of this method, consult the following report; B. Virely, 'Artificialisation, de la mesure à l'action', Thema, CGDD, 2017.
[8] Roads, like the diffuse building, are difficult to locate with remote sensing without going through very high resolution. The BDTOPO vector data from the IGN provide one of the other main sources of complementary data to take into account this type of artificialisation and are frequently used by the local authorities' urban planning services for the improvement of the MOS.
[9] We also speak of land documentation or literal documentation of the cadastre.
[10] https://urbansimul.paca.inra.fr/urbansimul

complementary data such as future transport networks or translate future planning strategies to produce more or less contrasting scenarios. Their application is not always possible with socio-economic data, but there is a relatively systematic use of the most easily accessible geographical data (distance to road networks, topography, land suitable for occupancy etc.).

The interest in this type of approach is based on the mapping of the possible future of land take in order to be able to evaluate, in a quantitative way, their impacts on the urban climate, the surface runoff, green fields etc. Modelling is also used as a means of explaining 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 is clear that the operational character of the predictive modelling is still in its infancy and there exist a number of unresolved issues.

1.2. Measurements and trends of land take in France

Studies on the analysis of land-use shifts towards urban or other types of land take reflect the global trend towards land take. This land take has been to the detriment of various types of land use: agricultural or vegetated land, forests, 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 typical transitions (1.2.1). These very different estimates (1.2.2) show that the trends in land take are nevertheless consistent (1.2.3) and place France in the average of the European countries (1.2.4).

1.2.1. 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 address the question from an analysis of the distribution of the whole territory between the various land uses. The land files, especially from the cadastre, are more directly focused on private property, built or undeveloped: they ignore public land and transport infrastructure. Farm structure surveys focus on the shrinkage of the territory dedicated to agricultural production and only allow a very indirect understanding of land take. Finally, the SAFER data, which identifies agricultural areas that could be converted into building surfaces, focus on the loss of agricultural land more directly attributable to urban development.

Name of the tool	CORINE Land Cover	Teruti et Teruti-Lucas	Land files	Census MAA	SAFER 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 SAU and Farm Structure (ESEA)	Declarations of intent to convert and transfer, SAFER
Origin / custodian / data accessibility	SOeS-CGDD Freely accessable	SSP-MAA Freely accessable	DGFiP/ Cerema Accessable with conditions	MAA Access?	SAFER Access?
Spatial resolution	25 ha/100 m (5 ha for changes) homogeneous occupation	Data: 309,000 points (3-40 m²) grouped into 31,500 clusters. Pas précis à éch. < dépt	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 no time 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	57 categories combining occupation and land use	13 categories	Agriculture	Areas likely to be urbanized, estimated from land markets for areas for urbanization, houses in the countryside and residential and leisure areas
Waterproofing	Yes, for 2012 with CLC HR	Yes, by interpretation	No	No	No
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: 'CLC HR soil sealing'	Increase in the number of points			
Application	Good mapping of the OS (1:100K, raster 100 m) Possible European comparisons (38 countries)	Progression of land take in France as Statistics (no maps) in timely fashion. 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

Table 1-1. Comparison of different tools for measuring land take in France

1.2.2. Differing estimates of the extent of land take

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 source JRC to 5.1 million hectares according to Teruti-Lucas, and 3 million hectares in 2012 according to Corine Land Cover.

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 MAAF)*	4,6 Mha en 2006 5,1 Mha en 2014	61 200 ha /an entre 2006 et 2014
Corine Land Cover (source MEEM, CGDD)**	2,5 Mha en 1990 2,7 Mha en 2000 2,9 Mha en 2006 3,0 Mha en 2012	20 000 ha/an entre 1990 et 2000 33 000 ha/an entre 2000 et 2006 16 000 ha/an entre 2006 et 2012
Global Human Settlement Layer (GHSL) Landsat and other complementary data (photo and census data) (source JRC)	1,04 Mha en 1975 1,75 Mha en 1990 2,03 Mha en 2000 2,35 Mha en 2014	47 000 ha/an entre 1975 et 1990 28 000 ha/an entre 1990 et 2000 23 300 ha/an entre 2000 et 2014
Land files - MEEM – DGALN-DHUP*** - Cerema ****	- -	33 300 ha/an entre 2000 et 2010 31 800 ha/an entre 2006 et 2010 27 500 ha/an entre 2006 et 2015
Land market SAFER***		83 981 ha/an entre 2000 et 2012

* Agreste, figures and data N° 229, March 2015, land use in 2014
** Update, land use in France, CGDD n°219, décembre 2015
*** Overview of the quantification of national changes in agricultural surfaces, May 2014
**** The consumption of space and its determinants according to the DGFiP's land files, analysis and inventory as of 1er January 2015, December 2016 (for this method, non-cadastral land is not considered).

Table 1-2. Various estimates of the level of land take in France and its changes

These very significant differences arise from the differing objectives, methods and data sources. In the European source, based on the interpretation of remote sensing imagery, there is the interest 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, 5 ha for the extensions to artificialized land). Their shapes and positions are arbitrary because they adapt to the contour of areas identified as land uses homogeneous. Although this dataset allows accurate measures of land take in densely-populated and homogeneous areas (from the perspective of both buildings and other waterproofing covers), such a level of resolution can underestimate land take in sparsely-populated areas by excluding hamlets, scattered settlements or facilities and small road elements (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 apply to at a broader spatial scale (whole territory and administrative regions), with the representativeness of the data becoming lower in smaller areas.

Other sources and methods exist but are applied more locally. This is the case in Île-de-France with the IAU-IDF MOS (Land Use Methods). The development and integration of all available data sources (cadastral data, IGN topographic data, new high-resolution satellite images, etc.) may allow a substantial improvement towards more precise land take measurement in France.

Box 1-2 - Example of the differences in land cover estimation between MOS (Mode d'occupation du sol) and the CLC

Figure 1-2 illustrates the differences in estimation of MOS and CLC. The red circle shows a hamlet present in the MOS and not in CLC, surely because of the threshold (25 ha) while the built areas within the impermeable areas are visible in the CLC-HR on the right. In addition, the area under the purple polygon is classified as 'artificial open space' in the MOS whereas it is classified as 'arable land' in CLC.

It is the spatial thresholds and classification that explain the difference in classification between the two data sources.

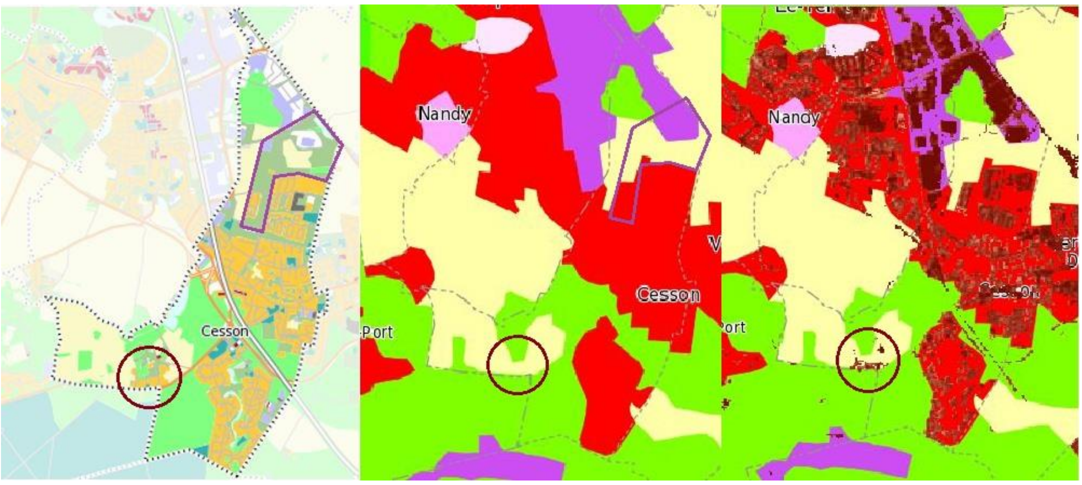


Figure 1-2. MOS- 201 (left), CLC 2012 (centre) and CLC-HR 2012 (right)

1.2.3. General land take trends are very consistent nonetheless

Despite these differences in estimations, and therefore 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 into 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 (4.1 % of the national territory) (Table 1-3 and Figure 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 evolved 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 outside the urban fabric, have increased over the same period by 8%, reaching nearly 400,000 ha in 2012.

	2006			2012		
	Mha	%	%	Mha	%	%
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 & 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
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**

Table 1-3. Distribution of the area of mainland France by nature of occupancy according to Corine Land Cover 2006 (corrected data) and 2012. Source: SOeS, MTES.

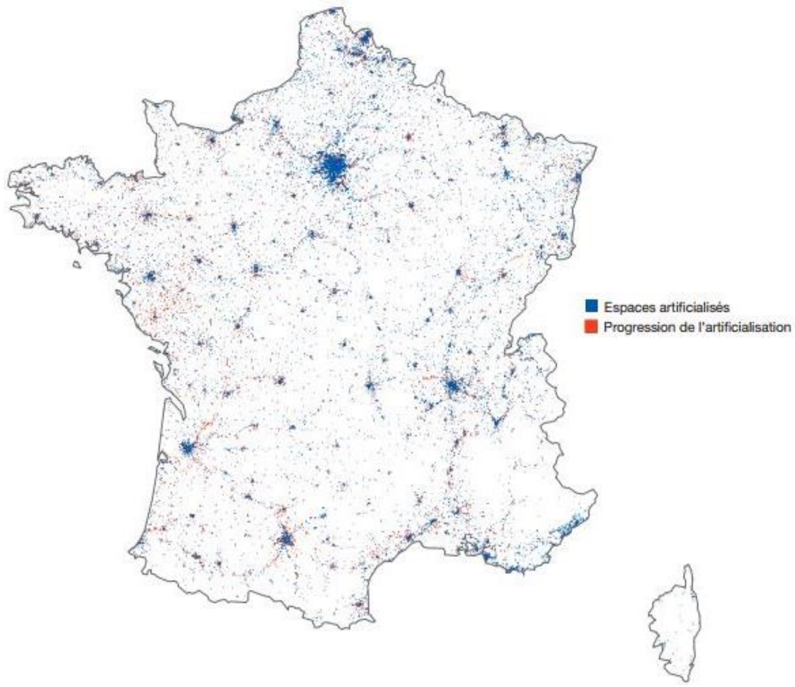


Figure 1-3. Land take between 2006 and 2012, calculated from CLC data.
Source: UE-SOeS, Corine Land Cover, 2012
Note: change polygons have been thickened for display

Similarly, Teruti and Teruti-Lucas annual data highlight a continuous increase in areas classified as artificialized over the entire period from 1984 to 2014 (Figure 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) and confirmed in 2014. This annual flow of 50,000 to 80,000 ha / year reflects the reverse flow of farmland losses oscillating between -40,000 ha and -100 000 ha / year depending on the years, with 'natural' land being in the intermediate position, losing or gaining area through the years.

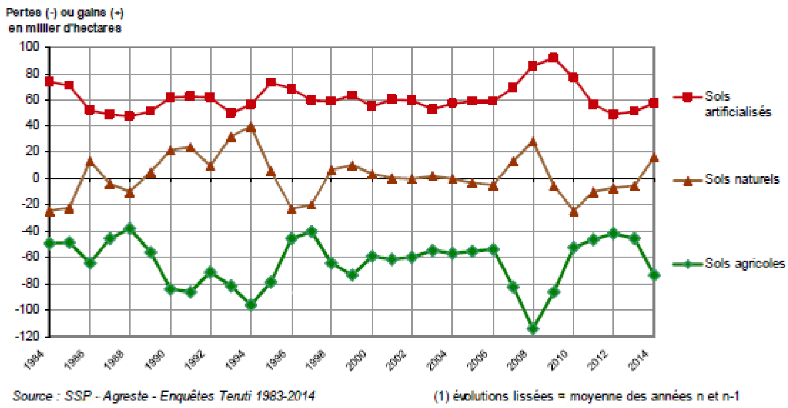


Figure 1-4. Evolution of annual increase or decrease in area according to occupancy, according to Teruti et Teruti-Lucas

This source also allows an important assessment of the surface coverage, with a distinction between impermeable and permeable surfaces (Table 1-4). Thus, in 2014, of the 5.1 million hectares considered in France as artificialized, 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 more recent period (2006-2014), the built-up soils have increased to the greatest extent (+ 22%), while coated or stabilized soils have increased by 14%, while artificial or grass-covered soils have not increased more 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.

	2006			2014		
	Mha	%	%	Mha	%	%
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 artificial 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**

Table 1-4. Distribution of mainland France areas by nature of occupancy according to Teruti-Lucas surveys 2006 and 2014. Source: SSP, MAA.

Land records show, for their part, a slight increase in the 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 50,000 and 60,000 ha per year (Land Markets Report, FNSAFER 2017).

To summarise, the average annual rate of land take within the French territory increased sharply in the 2000s, up to a peak (2008/2009); it then declined until 2014, before again increasing in 2015 and continuing into 2016.

Many studies are done at more local scales, thus providing finer-scale 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 (Figure 1-5).

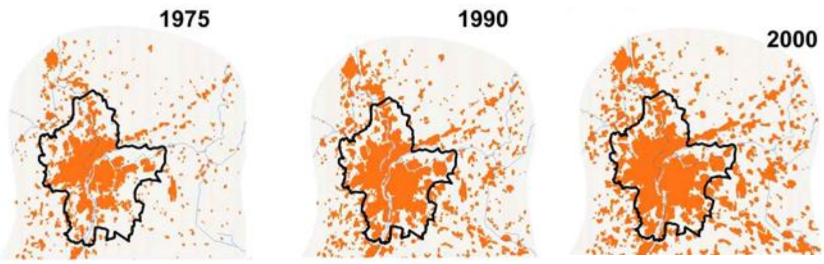


Figure 1-5. Expansion of impermeable surfaces in the Lyon agglomeration between 1975 and 2000 (Source : IRSTEA)

Similarly, the IAU-IdF study on artificial soil in Île-de-France shows changes in different types of surfaces between 1982 and 2012, as well as focusing analysis on specific changes between categories from 1999 to 2012 (Colsaet 2017) [11]. 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 a primary slowdown phase in the growth of artificialized areas (1999-2008), a strong break occurs between 2008 and 2012, during which time the slowdown in 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 recently had been growing rapidly.

Table 1-5. Overall change in major land uses over time in Île de France (figures in ha per annum) Source : IAU-ÎdF pour les données du MOS, analyse Colsaet (2017)

Evolution en hectares annuels	1982-1999	1999-2008	2008-2012
Espaces agricoles	**-1 806**	**-1 870**	**-796**
dont terres labourées	*-1 777*	*-3 416*	*-252*
dont prairies	*-60*	*1 490*	*-504*
dont autres	*31*	*56*	*-39*
Espaces naturels	**-409**	**660**	**153**
dont forêts	*-165*	*-138*	*83*
dont espaces ouverts	*-338*	*724*	*44*
dont surfaces en eau	*94*	*73*	*26*
Espaces artificialisés	**2 214**	**1 209**	**643**
dont espaces ouverts	*549*	*274*	*-148*
dont espaces revêtus ou bâtis	*1 700*	*1 193*	*707*
dont carrières, décharges et chantiers	*-35*	*-257*	*84*

[11] Table, figure and analysis from the report: Colsaet, A. 2017. *Gérer l'artificialisation des sols : une analyse du point de vue de la biodiversité*. Rapport, Institut du Développement Durable et des Relations Internationales (Iddri), Paris, France, 105 p.

The analysis of conversion between categories between 1999 and 2012 illustrates the high complexity of these changes and the importance of changes in opposing directions (Figure 1-6). Thus, the loss of agricultural land is not limited, even in Île-de-France, to a simple artificialization of agricultural land. While a large area of agricultural land has been converted to build buildings or be covered, a significant area of agricultural land, up to 700 ha / year, has at the same time been converted into natural areas, with forested areas having little involvement in these changes (Colsaet, 2017).

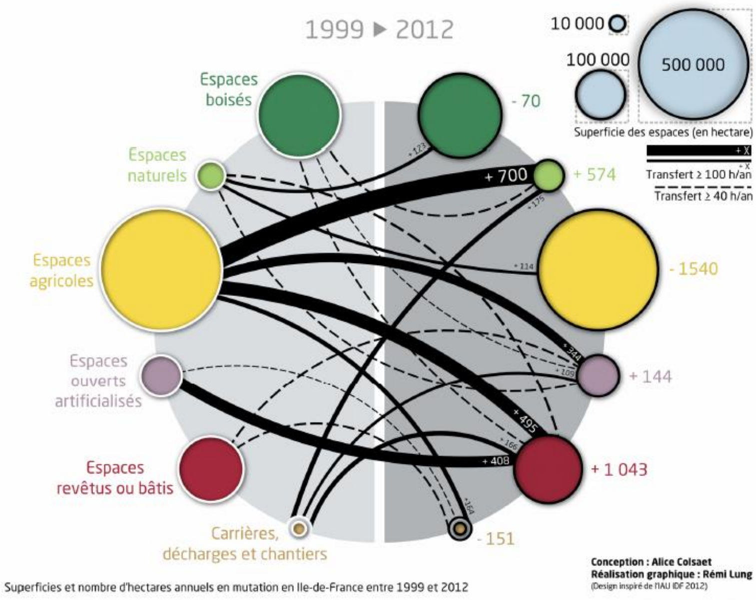
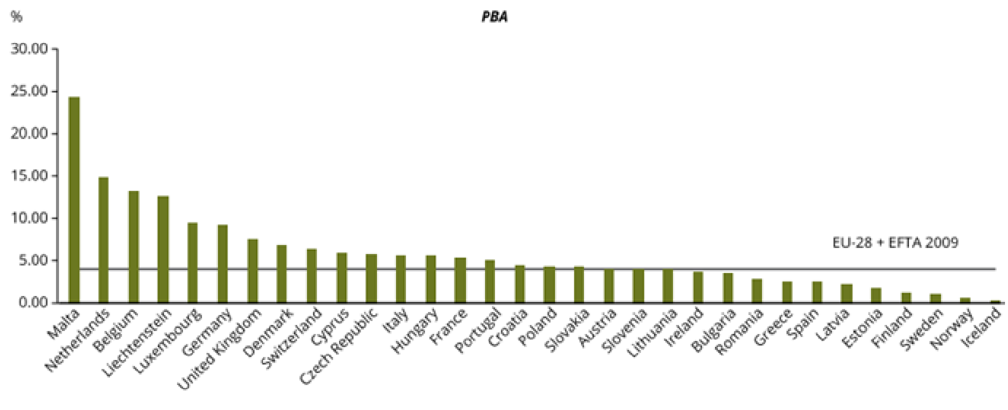


Figure 1-6. Net and gross land use changes in Ile-de-France, between 1999 and 2012 (Colsaet, 2017)

1.2.4. 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, around the European average. This pace is similar to that of Italy, about 5 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.

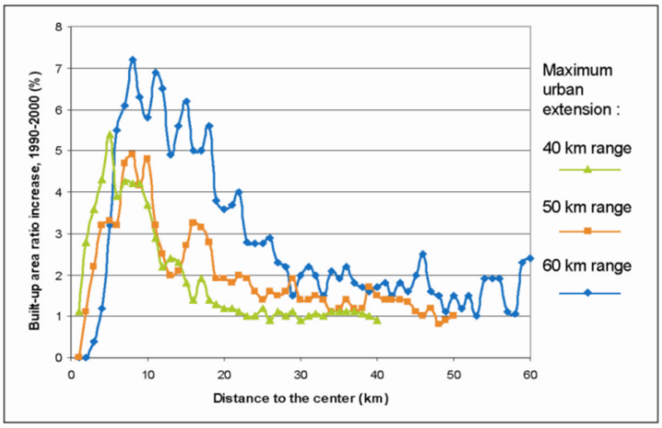
Focusing on the built-up portion of the impermeable soils (Figure 1-7), the proportion of French land that is built-up is also close to the European average (5% in 2009). This is in contrast to the Netherlands (15%), Belgium (13%) or even Germany (9%) and England (7.5%), whose built-up footprint covers a much larger proportion of the land. Conversely, the Scandinavian countries, Ireland, and also Spain (2.5%) have proportionately less built-up area.



Note: The horizontal line indicates the overall value for Europe (EU-28 + 4). The countries are ordered (in all four parts) by decreasing values.

Figure 1-7. Percentage of the total land area built-up by country in Europe, in 2009. *Source : EEA, 2016*

As noted 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. But if this translates into significant growth in built-up areas at any point on the periphery, the highest growth rates of built-up areas can be seen at the immediate limits of the 40 urban agglomerations (Figure 1-8).



Thus, **in Europe, sprawl mostly occurs on the periphery of the zones already built rather than more distant areas.**

Figure 1-8. Changes in the urbanized surfaces of 40 European cities from 1990-2000: densification at the margins of these agglomerations. Source: Guérois, Pumain, 2008

X axis: distance to the centre of the city (historical centre); Y axis: relative increase of urbanized areas between 1990 and 2000 compared to 1990, in%. The measurement is carried out within concentric rings of 1km increments.

1.3. 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 urbanized 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. In the same way, 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 soil land take beyond the city's 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 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 the processes to control the costs, while setting an appropriate input rate. The IGN creates a complete orthophotographic coverage of France every 4 years, a possible temporal scale that might be adopted. The process proposed by the IGN for the creation of an IGN Large Scale land cover layer (OSC GE) and applied on the former Midi-Pyrenees 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

This chapter deals with the impact of land take on the characteristics and properties of soils in the pedological sense, distinguishing on the one hand the **physical, physicochemical and chemical aspects** (2.1), and on the other hand, the **Biological aspects and Biodiversity of Soil Organisms** (2.2) (plant and animal biodiversity at the landscape scale will be discussed in Chapter 3). An important difficulty encountered in this analysis of the scientific literature comes from the great diversity of the locations and issues and the frequent absence 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 ...) or predicted in the case of rehabilitated soil. This categorization is largely insufficient to answer all of the questions because it aggregates very different situations. However, in this chapter we propose a draft classification combining use and pedological characterization that remains to be formally consolidated (Table 2.1), and we identify this issue as a research priority.

2.1. 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 (Figure 2-1). At the same time, the 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 man-made environments have been identified as being important to maintain: water cycle regulation, 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.

Box 2-1 – Analysis of the literature

The analysed literature comprises 273 references. The vast majority of articles deal with the analysis of soil properties measured on an actual site with an approach essentially intended to establish a 'diagnosis' (size of the urban area, gradient of urbanization, mining site ...) The literature was quantified according to the SUITMA category.

Only 59 of these references specifically report soil characteristics (overall physical and chemical characteristics) of artificialized land. Most of these 59 studies are very recent (Figure 2-1), and almost a third was produced in Europe (only 3 in France), the others mostly originating from the United States and Southeast Asia.

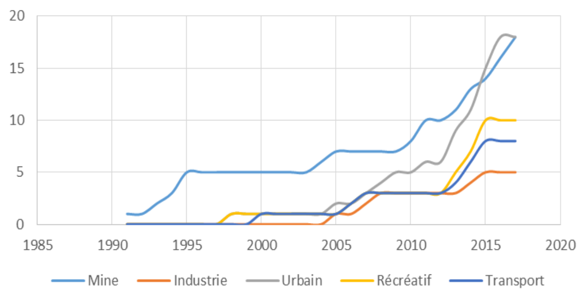


Figure 2-1. Publication dates of the 59 studies specifically reporting pedological and physicochemical characteristics of the different SUITMA classes (cumulative numbers since 1990)

2.1.1. Characteristics and classification of artificialized soils

• Characteristics of artificialized soils

Soils within artificialized areas are of two different natures: soils in place, called 'natural', but which undergo the consequences of the 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.). Humans 1) transform by mixing, compacting or aerating layers of materials, 2) excavate and export soil materials leading to their partial or total removal, 3) import earthy or technogenic exogenous materials (minerals, rubble, industrial or household waste etc.), which rapidly transform the evolution kinetics of the material, and finally 4) seal the surfaces by 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 contributions of technogenic materials and the processes of 'soil engineering' sometimes implemented to give the soil new functions or to restore lost functions. These artificialized soils cover a wide range of pedological realities, ranging from natural soils located in artificialized zones (some parks, allotment gardens, peri-urban agriculture ...), to more or less truncated soils and / or enriched with technogenic materials, to soils constructed from earthy and / or technogenic materials during development work or soil rehabilitation.

• Typology of artificial soils in classifications

The classification of artificial soils relates to those for which the main pedological factor is man, 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 of the soils: it proceeds by analysis of its profile, which is structured in horizons that reflect the processes of pedogenesis that creates its properties. Pedological references mainly refer to forest (undisturbed) or agricultural soils, however some soil references have recently incorporated artificialized soils into their typologies.

In the French Soil Reference Manual (RPF, 2008), artificial soils are called Anthroposols. They are either soils of natural origin so transformed by anthropogenic processes that they can no longer be linked to the original soil or to other natural references (transformed anthroposols), or soils manufactured by man (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 remain based on soil morphology linked to human interventions. It seemed essential to integrate land use into these classifications in order to better quantify the potential and services to be obtained from each soil (Morel et al. 2014), hence the definition of SUITMAs (Table 2.1).

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 the soils studied to be linked to these two main categories. In addition, it would be desirable to be able to distinguish between the different types of urban soil, in particular those of gardens (private or collective), parks and urban forests, approaches to buildings or roads, paved and built soils. Indeed, soil characteristics depend a lot on practices, garden soils, for example, being very fertile overall, rich in organic matter, and contaminated with certain specific pollutants (pesticides) while 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 and an absence of risk of contamination of surface water or contamination of food for built or coated soils, etc. However, this distinction has not been possible in view of the available literature in which the vast majority of soils are described as 'urban' or 'in residential areas', without further information.

Soil type RPF SUITMA	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

Table 2-1. SUITMA categories and soil types defined by the French Soil Reference System (RPF, 2008)

To illustrate, Figure 2-2 shows the variability of the horizons of artificial soils according to the category in which they belong.

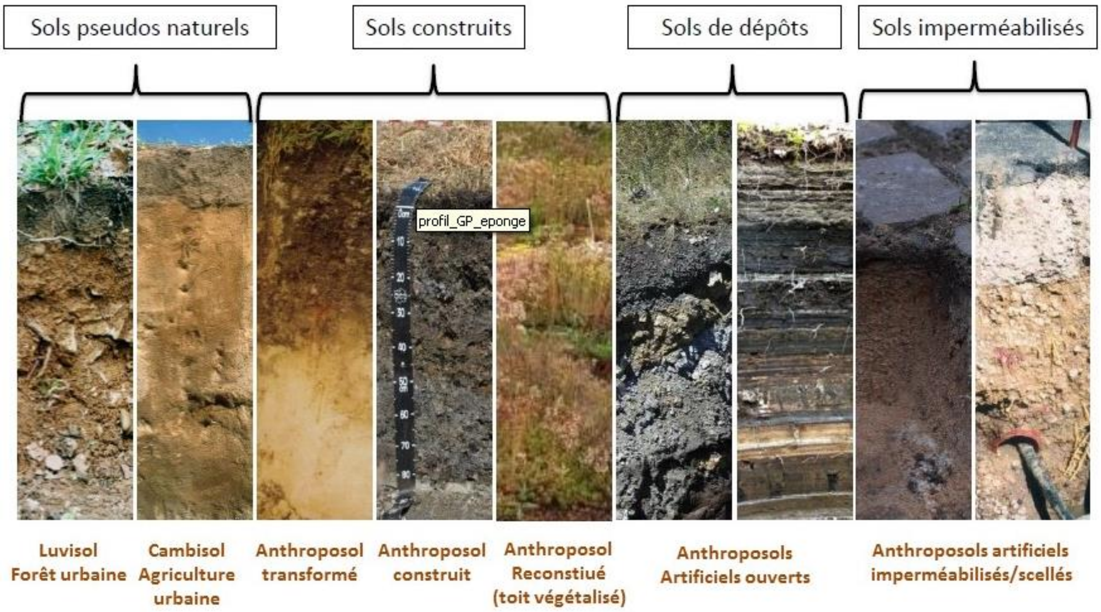


Figure 2-2: The range of urban influence on soils (Photos : C. Schwartz)

2.1.2. Characteristics and properties of artificial soils

Although these soils are significantly modified by humans, and often dominated by the presence of artificial materials, artificial soils are currently characterised using the same physical and physico-chemical criteria as for natural soils.

The analysis and interpretation of changes in soil characteristics linked to land take must be associated with a 'reference' situation that is very difficult to define. In the publications reviewed, the 'reference' soils are either agricultural (in 20 to 30% of cases) or forest soils close to the study area. But reference land use is not specified in more than half of the cases and there is often no reference land. Comparison with an adjacent agricultural soil can be justified insofar as the majority of artificial soils are 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 assessment over time.

• Physical and morphological characteristics influencing water transfer and plant growth

Soil infiltration capacity is one of the main properties affected by artificialization. It is associated with very important issues: runoff, and therefore the risks of flooding, and water erosion (see 3.2). It is estimated that 60 to 70% of artificial soils are sealed, 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 strong stoniness due to the contribution of allochthonous/exogenous materials (demolition materials, landfill waste, and mine waste). 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 infrastructures, 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, with 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 weaken the soil structure and expose it directly to the 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 is established and protected. 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.).

• High spatial heterogeneity makes comparisons between soils difficult

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 soil 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 apparent 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 technical materials (concrete, cement, etc.), which are common in urban soils and in infrastructure. There are also acidic artificial soils, particularly metalliferous and industrial mining soils, which can even have very acidic pHs (< 4) in more than 40% of cases.

• The dynamics of organic carbon is heterogeneous.

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

Several French studies have shown that open 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. Thus, the waterproofing of a soil can reduce the stock of C because it results in a stripping of the surface layer which is generally more organic and by the absence of introduction of 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 carbon stocks are dependent on the type and age of the vegetation cover. They will be higher in a mixed urban forest than in a hardwood or softwood forest only. Soil surface horizons under urban lawns (10-30 cm deep) can sequester up to twice as much carbon as forest soils this would be linked to the higher root biomass of grasses in the first 30 cm of soil, and to intensive grassland management (mowing, watering, fertilization) that increases root production. The carbon cycle in urban soils is also affected by compaction, which limits the root development of trees and thus their carbon storage. Macrofauna (especially earthworms), on the other hand, accelerates the decomposition and mixing of carbon monoxide and increases the carbon content of the first soil horizon. At present, the research focuses mainly on instantaneous stock calculations, but possibly diachronically in the future. Some more recent work is beginning to address the dynamic aspect by combining it with carbon dynamics modelling.

• The significant pollution from metallic and metalloid trace elements (MTE)

MTEs are the pollutants that have been most measured and studied in industrial, urban and mining soils. The metals followed 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, mainly in the surface layer of soils (up to 20 cm deep), in MTE compared to 'control' areas (agricultural areas, parks far 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, global pollutant load index). The approaches are numerous: they take as reference values extracted from the literature, national or more local measured values, or regulatory thresholds existing in the country or defined at European or international level. Overall, there is a link between the densities of urbanization, the age of the artificial soil and the concentration of metals in the soil. However, two distinct situations are identified:

– Diffuse pollution may occur 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 use a global 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 modifies 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 mixed materials 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 those measured in urban areas on average, and these soils, whether on the surface or buried at depth historically, present real risks of contamination for 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 area and the peri-urban areas has been demonstrated in recent years, but 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.

Urbanized soils are therefore known as interfaces for storing trace metals. Observations show that the solubility of metals and their potential mobility are generally low. Presenting characteristics favourable to the retention of metallic cations (carbonated soils, enriched in MO, vegetated), urban soils play the role of reservoirs for these MTEs that they have accumulated on the surface or in certain horizons for several centuries. A study carried out in Ile-de-France confirms and quantifies this storage of MTEs, and in particular cadmium (Box 2-2). In the case of metalloids, which have received very little attention in the literature with regard to artificial soils, the alkaline pHs of urbanized 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 areas 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 woods are much older (they date from the late 19th Century). The capacity of forest cover to increase the flow of certain ETM 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, they have not been exposed for as long to the urban conditions of ETM inputs.

Concentrations of anthropogenic MTEs increase from rural to urban areas (Figure 2-3), where they often reach or exceed regulatory thresholds. Heavy Cd pollution of urban wooded soils poses a significant risk to biological communities.

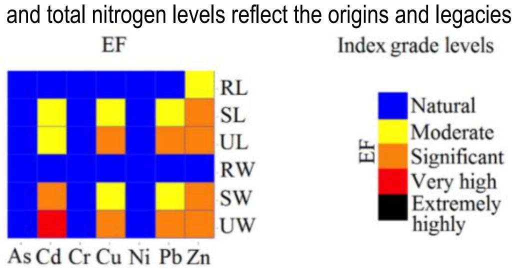


Figure 2-3. MTE increases in soils in Ile-de-France (source: Foti et al., 2017)

EF: enrichment factor, relative to the local geochemical baseline (presumed free of anthropogenic contamination)
R : rural, S : peri-urban, U : urban, L : lawn, W : wood

Box 2-3. The special case of urban garden soils

While many studies have highlighted the potential contamination of urban vegetable garden soils, their fertility, resulting from highly intensive and varied cultivation practices, must also be stressed. 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 levels of nutrients. But, they also have total metal contents that are, on average, twice as high; they are linked to the repeated use of fertilizers and pesticides (major source of pollution), solid waste inherited from former mining or industrial activities, and industrial, urban or automobile 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 quality of garden soils is generally highly variable. A recent study of 4 European cities showed, at the city and garden scale, that the variability observed for the main soil properties is dominated by local geology (parent material), and by gardening practices, which differ from one country to another. The range of MTE concentrations is similar for 3 of the 4 cities. Extreme values are observed for Cu, Pb and Zn which are mainly explained by the historical and environmental circumstances of the sites, showing the influence of the history of successive land uses, as well as contributions linked to external factors (industrial activities, road traffic, etc.).

- **Contamination by organic pollutants remains poorly known**

For over 20 years, studies have focused on urbanized or industrial soils, and measurements mainly concern total hydrocarbon and polycyclic aromatic hydrocarbon (PAH) concentrations and their fate. There is a abundant literature on the characteristics of PAHs in brownfield soils, but far fewer studies on urban soils. These measures are often coupled with those of the MTEs at the same sites as part of an overall assessment of the physico-chemical 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 to be retained are the same as for heavy metals. Artificial soils are areas where PAHs have been stored for almost 100 years on certain industrial sites, they are not very mobile because of their low solubility and in the same way depending on the type of input (atmospheric or direct input by PAH-rich waste), and the soils are highly contaminated or enriched only on the surface or in the horizons containing the waste.

Very recently, research has been initiated on certain emerging organic pollutants, with difficulties related to analytical methods (flame retardants such as polybrominated diphenyl ethers PBDEs, organochlorine pesticides, drug residues, etc.) due to the presence of these ultra-trace molecules, and sampling strategies not adapted to these molecules in highly 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 are instead devoted to 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.

- **Moving 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 not been proportionally evaluated 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 old agricultural soils), and on the other hand to try 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 aggregation of parameters with all associated details of the weighting of parameters to be retained. Studies presenting both indicators and their application to land use optimization are rare. However, indices with an integrative aim have developed considerably. However, they do not integrate many of the soil characteristics, but rather are mainly used to describe loss of soil functionality.

For example, the NAC (Natural pollutant attenuation capacity of urban soils) index combines the parameters % organic carbon, % clay, bulk density, pH and total nitrogen. If the index classes are well defined, it is possible to show trends between the NAC value and land cover type (Figure 2-4). NAC is also correlated with the age of artificialization (soil resilience-recovery concept).

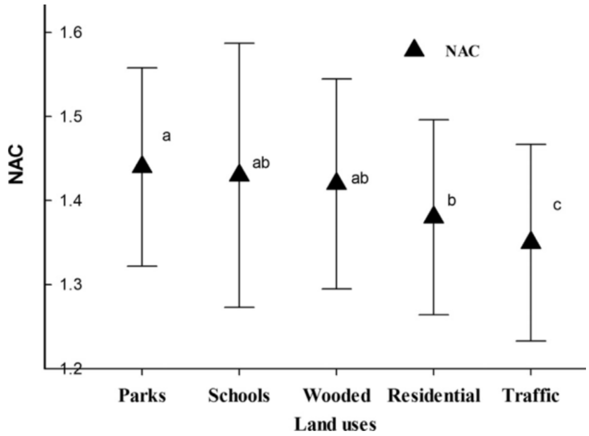


Figure 2-4. Natural attenuation capacity of urban land pollutants according to land use in the city of Beijing (Source: Wang et al., 2015). Dimensionless index; higher values indicate higher capacity. Values shown: mean ± standard deviation.

In France, discussions are ongoing concerning the possibilities of integrating the concept of soil quality into regional development projects. One example is the Uqualisol-ZU project (GESSOL programme), in which soil and its physico-chemical, microbiological and physical characteristics are considered 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 uses identified in the geographical area, has thus been designed (Keller et al. 2012). This versatile index has the advantage of being relatively easy for decision-makers to understand (Figure 2-5). This qualification of soils via synthetic indices is attracting growing interest. But there is still no consensus on the most relevant and essential parameters for describing the characteristics and potential of these soils. However, contamination regulations (exposure and health risk assessments for the population) seem to play a leading role in the characterization of these soils.

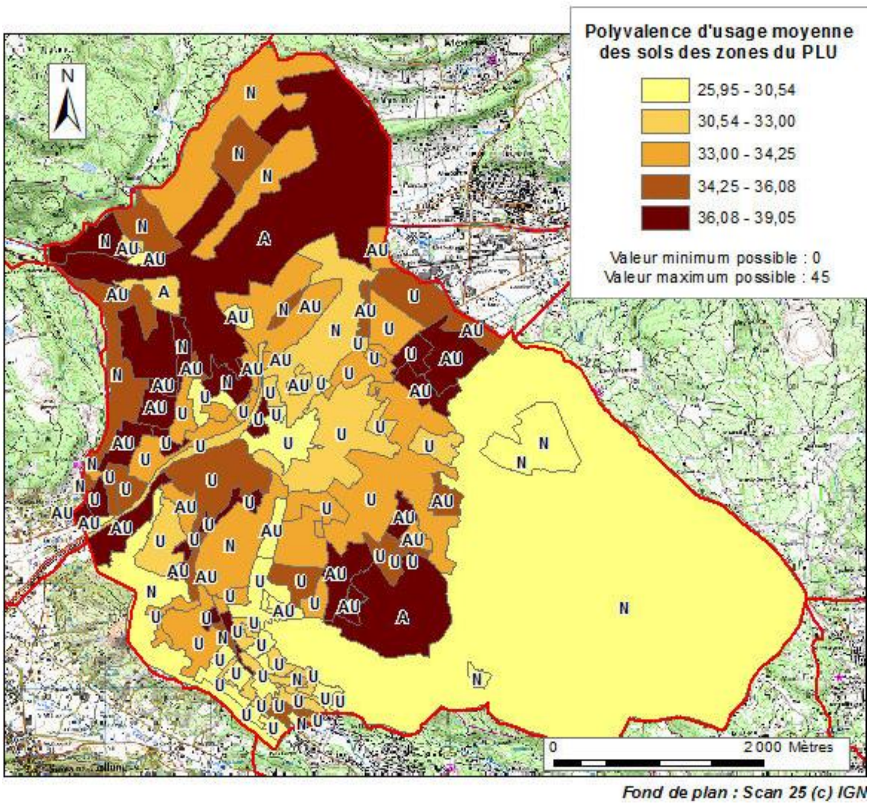


Figure 2-5 : Map of land use versatility by Gardanne PLU zones. The letters shown on the surfaces correspond to the PLU zoning: U: urban, A: agricultural, N: natural, AU: to be urbanized.

2.1.3. Summary of the physico-chemical characteristics of artificial soils

In summary, SUITMA is characterized by:

- extreme spatial variability linked to the complexity of their history, from the millimetre scale to the metric scale, 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 infrastructures, which frequently leads to high compaction rates;
- the nature of the technogenic materials they contain, their abundance, and their size;
- 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 zones) and devices dedicated to rainwater infiltration;
- pH levels frequently above 7 for urban soils and those of transport infrastructure, or on the contrary acids to very acids for mining and industrial soils;
- highly variable organic matter contents depending on soil use (high in open soils such as vegetable gardens and lawns, and low in urban and mining waterproofed areas) and its origin, but with contents in the surface layer on average higher than in unman-made soils;
- high concentrations of heavy metals (Pb, Zn, Cu, Cd, Ni), mainly on the surface, 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).

2.2. Impacts of land take on soil organisms and biodiversity

Because of their structure, and the diversity of their physicochemical characteristics and 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 presentation of the diversity of these organisms, species are grouped by size (Figure 2-6).

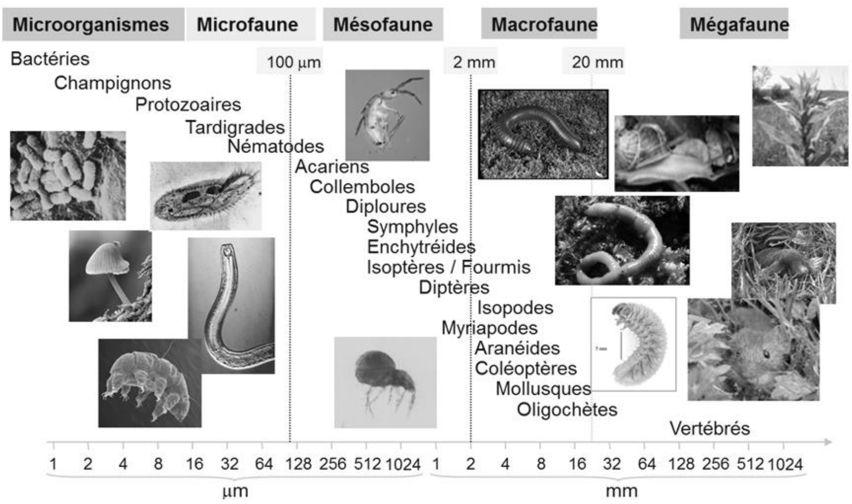


Figure 2-6. Illustration of the diversity of soil fauna, from the smallest organisms (bacteria, protozoa) to the largest (earthworms, amphibians, vertebrates). Source: Éric Blanchart (IRD)

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 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 Figure 2-6).

Box 2-4 - Analysis of the literature

The selected collection 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, 31% microorganisms). The most studied categories of land take are urbanisation and mining or industrial activities (Figure 2-7.A). Most studies are conducted at the community level. These soil microbial and animal communities can be characterized by various ecological indices: their abundance and biomass; their composition, taxonomic or functional; and their structure, taxonomic or functional (Figure 2-7.B).

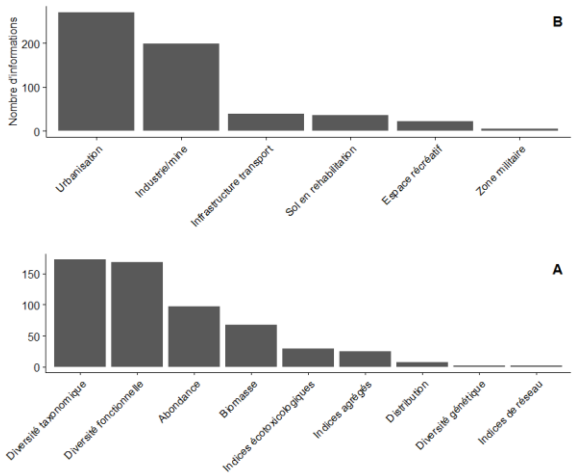


Figure 2-7. Land uses studied (A) and response variables measured (B) in the analysed literature

This corpus 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 corpus 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; 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 for all the relevant publications (see Figure 2-6).

2.2.1. Effects on different groups of organisms

The land take drivers are described very inconsistently in the articles. In the case of industrial mining activities and road infrastructures, it is possible to know relatively accurately what the environmental pressure gradient corresponds to (metal pollution, PAHs, etc.) or habitat destruction/fragmentation. But in almost all studies dealing with urbanization, it is often impossible to break down the contribution of the various factors of land take (fragmentation/disappearance of habitat, pollution, waterproofing, etc.). Moreover, most studies compare soils in urbanized 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 (2.2.2).

- **Effects on micro-organisms**

A synthesis of the effects of the different land take factors on diversity measures or on taxonomic groups of microorganisms shows that overall 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 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 disturbances (removal or mixing of soil horizons, waterproofing, compaction), chemical disturbances (atmospheric deposition, fertilization) or ecological disturbances (removal or replacement of vegetation) of soils, and it causes 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 carried by soils (soil fertility, water purification, Carbon sequestration etc.) The evaluation of the impact of soil artificialization on microbial diversity in the soil and on interaction networks remains very limited, whereas new mass-sequencing methods would 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 of soils.

- **Effects on meso- and micro-invertebrates**

The effects of the urban environment on micro and mesofauna vary according to the sampling sites and parameters measured, and according to the management of urban sites. Several studies show that biodiversity is more favoured in urban areas than in other highly human 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 collected in urban settings had a much higher biodiversity in collembola and mites than most agricultural soils. This is particularly the case for the soils of allotment gardens rich in organic matter, and which present a diversity of micro-habitats very favourable to the development of diversified communities. This is also the case for some particular ecosystems, which are created on vegetated roofs, stormwater management structures (retention/infiltration basins) or landfill. It would appear that Anthroposols can be improved so that they are more favourable to the development of biodiversity, in particular by strengthening organic matter inputs (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, carabids, ants, wood lice or other macro-invertebrates, the conclusions are consistent and allow us to draw a response pattern of the diversity of macro-invertebrates to the urbanization gradient. Positive outcomes emerge when looking at urban soil ageing or soil rehabilitation practices. Regarding response variables, the functional composition of communities is negatively impacted by all artificialization factors, making it a binary indicator (yes/no). The indices of taxonomic diversity, functional composition and abundance measures present a range of responses depending on the artificialization elements, and are therefore relevant for assessing the intensity of the different artificialization elements. It is therefore imperative to study the response to artificialization with a combination of biological/ecological indicators.

Macro-faunal soil communities in cities are dominated by a small number of species and tend to be composed of a smaller proportion of detritus feeders (soils less rich in organic matter) and forest species (even in forest habitats in cities). On the other hand, they are home to larger proportions of small individuals (energy constraints) with high dispersal capacities, preferring open, less humid and warmer habitats. Generalist species with broad biogeographic distributions are over-represented in urban areas. Similarly, exotic, invasive, or opportunistic species may find environments closer to their original biogeographical zone in urban environments, largely due to the urban microclimate.

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

2.2.2. 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 (Figure 2-8), 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 reversibility potential of the impact of artificialization on soil organisms, at least when such rehabilitation is possible. Among the most documented uses, the **soils of industrial and mining infrastructure and activities are the most strongly impacted overall** from the standpoint of soil organisms, both in terms of taxonomic diversity and composition. The few studies on impermeable soils (road surfaces, paving / paving in residential areas) always show very negative effects of waterproofing on soil microbial communities, in relation to the absence of vegetation, and the absence of exchanges (water, nutrients) with the surface. We have not found any studies concerning soil fauna, even though the latter is probably also heavily affected by this waterproofing.

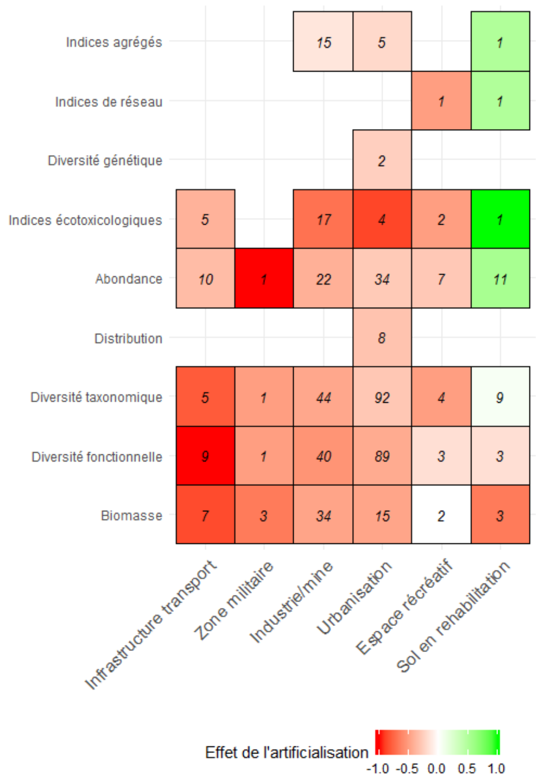


Figure 2-8. Effect of land use on response variables of all soil organisms. The X and Y values are given in Figure 2.5. The numbers in the boxes correspond to the number of cases.

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 microorganisms, 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 the resulting 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 and 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, 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 '**convergence of urban ecosystems**' suggests that anthropogenic factors (management, practices) are more important control factors than environmental factors (parental material/soil geological substrate, climate, etc.). In many studies, the increase in environmental pressure leads to a decrease in biodiversity values, according to the hypothesis of '**increasing disturbance**' as a function of the land take 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.

2.3. Conclusions: strategies to limit the impacts of artificialization on soil properties, and the reversibility of uses

The impact of land take on the physical, chemical and biological properties of soils, enabling them to continue to perform all 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 TL), the **potential for intervention** is reduced: the reduction of impacts depends on the 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 (Figure 2.9). 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[12].

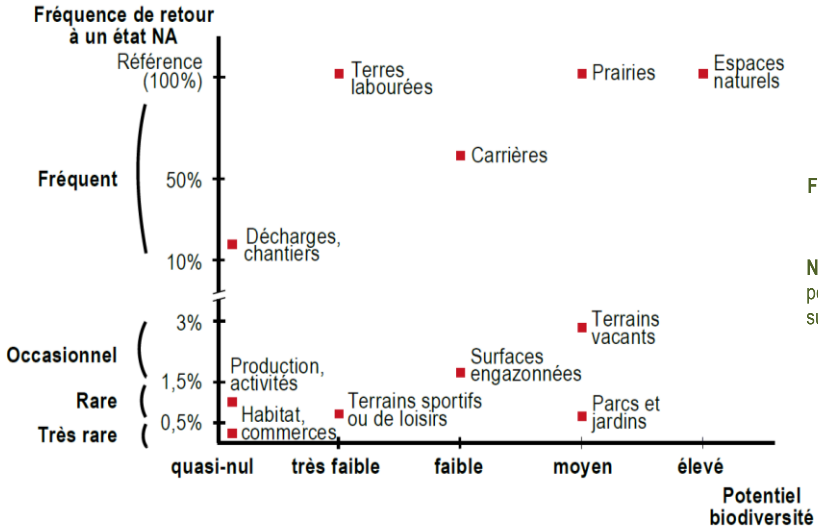


Figure 2.9: Biodiversity potential and frequency of return to a non-artificial state observed in Île-de-France over the period 1999-2012 (after Colsaet, 2017).

NB : Uses are based on MOS IdF and the biodiversity potential corresponds to the BioMos indicator (average suitability for biodiversity, according to experts)

For other waterproofed soils, **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 impermeability and erosion risks 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 (sand with a high organic matter content). This system acts as a rainwater filter and favours flows between the surface and the ground; however, it tends to become clogged as it ages. Such an option concerns more specifically parking areas and areas peripheral to transport infrastructure or logistics warehouses and therefore represents significant potential. **Drainage ditch systems** are particularly important because they can improve both reinfiltration and sediment trapping. However, their effectiveness may decrease over time in the absence of maintenance due to accumulation of deposits. They also constitute 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 also 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 waterproofed, bare or grassed/vegetated, which, according to TL, 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 has the **greatest potential for limiting environmental impacts and for reversibility**. Figure 2.9 illustrates the significant effective reversibility of quarries or landfills, in particular, bearing in mind that in the classification adopted, 'reversibility' does not mean that the soil has neccesarily 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-erosive methods in urban areas**, such as

[12] EEA Report, 2016. *Land recycling in Europe -Approaches to measuring extent and impacts*. No 31/2016. Luxembourg: Publications Office of the European Union, doi:10.2800/503177

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 inappropriate and, in particular, too late techniques (60-80% of erosion occurring during the initial construction phase).

For these unsealed soils, an initial application of **organic matter** (OM) in large quantities, or several successive inputs when possible in artificial areas, appears to be effective in maintaining or building carbon stocks in artificial soils and directly improving certain functions such as water retention capacity, 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 60 cm of compost added at a depth of 60 cm allows, after 4 years, the formation of stable aggregates, between 15 and 30 cm, in which the organic matter is protected.

Mining soils are relatively unstable and inconsistent due to their texture, coarse element load and reduced nutrient and organic matter content. All studies conclude that **mining areas need to be remediated** to limit erosion and pollution risks, and to allow rapid vegetation establishment. The remediation of these soils involves the addition of soil improvers (to correct the pH, and improve the OM and CEC) and fertilizers. These inputs make it possible to reduce the phyto-availability of MTEs and to increase biological activity and fertility, thus favouring the establishment of spontaneous or planted vegetation, which in turn leads to a certain reversibility of soil degradation.

Industrial wastelands are characterised by a wide diversity of sources of contamination, resulting in predominantly mineral or organic soil pollution and 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 industrial wastelands can again provide ecosystem services.

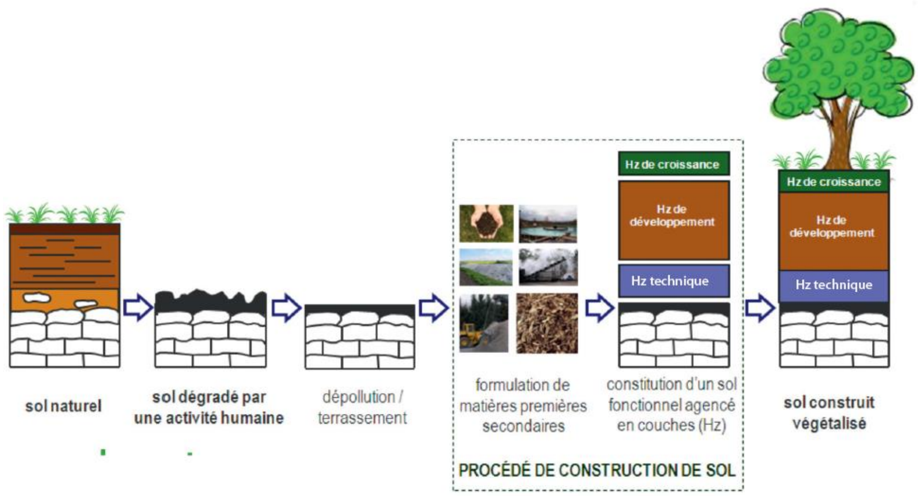


Figure 2.10 : Diagram illustrating the different stages in the implementation of soil engineering for soil construction and ecological re-functioning of degraded sites (after Séré et al., 2008).

Soil construction is a **soil engineering process** (Figure 2.10) 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 developing materials between them in order to build functional soils with the required properties, allowing the production of different 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.

2. 4. 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 disappearance and fragmentation, waterproofing; 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 that defines reference frameworks (complete soil profiles) and considers the types of technogenic materials that make up soils and the history of soil formation. This approach would clarify the sampling strategy linked to statistical methods relevant to the objective.

• Develop a strong consideration of **reference situations** (or 'controls'), the choice of which strongly guides 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 focuses mainly on polluted artificial soils, but relatively less on unpolluted soils.

• Systematically associate **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 in order to provide the tools to observe and quantify the impact of land take on soil evolution, to model this, and thus associate data on land use, demographic and economic growth, and the typology of uses with these profiles. This requires the establishment of **monitoring centres** for measuring the quality of artificial soils (the RMQS can be a basis for development) to produce databases useful to the scientific community and soil management stakeholders. The evaluation of **soil 'restoration' practices** after development should be made systematic with a before/after approach in order to be able to establish 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.

• To 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.

• To 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).

• Increase knowledge of **taxonomic groups other than collembola and nematodes** (even if the latter are very representative of their group), such as mites or protozoa. On the other hand, the concentration of humans (and domestic and synanthropic animals) in cities considerably increases exposure to pathogens whose development would be favoured by the urban heat island, by a developing topic. The advent of environmental metagenomics could compensate for the lack of specialists in each of the faunal groups by allowing high-throughput analyses of soil biodiversity.

• Explore the effects of the **urban landscape matrix**. Although 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 impacts of land take on the characteristics and functioning of artificialized environments

This chapter deals with the impact of land take on different characteristics and on the functioning of artificialized environments, discussed here at a broader scale than in the previous chapter, such as at the scale of the landscape, watershed or urban district etc. The first section deals with the **impacts of land take on landscapes, habitats and plant and animal species** (3.1). In the second part, the impacts of soil artificialization on **urban hydrology and urban stormwater management** are discussed (3.2). The third part groups together, as stated in the introduction to this synthesis, various more indirect impacts on the urban physical environment which, if it is possible to limit them, may influence the peri-urbanization phenomena and the resulting land take of soils. The three components studied more specifically concern the **urban microclimate, air quality and the noise environment** (3.3). As will be seen, these different fields share many aspects, and particularly the fundamental role of vegetation, which underlines the importance of a multidisciplinary approach to controlling the environmental impacts of soil land take.

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

Landscape ecology defines landscapes as areas at a scale of kilometres composed of different types of land use, 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 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 infrastructures that fragment them, and indirectly by the consequences of resulting 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 (cf. sections 3.2 and 3.3).

Box - Analysis of the literature

The environmental impact of land take on habitats and terrestrial biodiversity was assessed using more than 300 references. The taxonomic level and diversity under consideration are highly variable. Some studies focus on a single species, while others compare communities. Most of the work is specialized in the study either of vegetation or of an animal community. While studies focusing on fauna are mainly carried out in temperate climate regions, those on vegetation represent more varied climatic domains, including the Mediterranean region.

These references were analysed according to a grid aimed at distinguishing the areas of agreement between the work, and the positive or negative effects of land take according to the habitats and species concerned. As a second step, the results were quantified in a meta-analysis detailing the effects of urbanization and fragmentation on habitats and species (see Figure 3-1).

3.1.1. Methodology for analysing the impact of land take on habitats and biodiversity

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 the life cycle of species (especially food resources for wildlife), or even by their surface area (animals require a home range of varying size depending on the species).

Biodiversity is considered according to different levels of organization: genetic diversity, species diversity within living communities, or ecosystem diversity. To implement this type of analysis, the authors generally use tools and concepts derived from landscape ecology and in particular landscape indices, urban ecology, as well as the 'metacommunity theory' that links local factors (biotic and abiotic) within a habitat and landscape factors affecting the dispersion of communities.

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 urbanization, this environmental filter results from a combination of factors acting at the local and landscape scales. Factors acting at the local scale include the creation of **very specific habitats** (redesigned, constructed or impermeable surfaces, a high proportion of buildings or gardens) and **disturbances linked to anthropic practices** (introduction of exotic species, mechanical or chemical maintenance of surfaces, trampling, and disturbance). Factors at the landscape scale include the **isolation of favourable habitats** for species and the **effect of barriers** hindering 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, and even thrive and become abundant, in artificial environments. This selective effect generally results in a decrease in overall floristic or faunal richness and diversity. However, along urban density gradients, it is possible to observe at the interface between agricultural/natural and urban environments a mixing zone between two pools of species, those favoured by urbanization and those specific to natural or agricultural environments. This explains why the loss of specific and functional diversity is not always correlated with land take.

One hypothesis arising from this selective environmental filtering effect is that of a **homogenisation of living communities** associated with land take, i.e. a reduction in the diversity existing between the various habitats scattered throughout the urban matrix. Finally, a final hypothesis concerns the effects of land take on the genetic diversity of species and their reproductive success. It is assumed that high habitat fragmentation of a species will be detrimental to its mobility and 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 a plant species.

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

3.1.2. Effects of land take on habitats, and their fragmentation

Habitats are fragmented and removed by land take, which may also create new habitats. 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 does not only lead to a degradation and disappearance of habitats: it also creates new urban habitats such as green spaces, parks and gardens, the roles of which must 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 these infrastructures are mentioned explicitly. However, fragmentation is not directly proportional to the importance of the infrastructure concerned. The effect of transport infrastructures is not only structural (fragmentation), but also causes physical and chemical changes in the surrounding environment.

In addition to land use, spatial configuration is important. For an equivalent area of habitat lost, the impact on the loss of connectivity between favourable habitat patches varies according to the density of habitat areas, the distance between them and the presence of linear landscape elements such as a corridor, for example.

3.1.3. Effects of land take on plant species and communities

The significant 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 the 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, plant species also depend on landscape parameters, which may or may not facilitate the dispersion of their pollen or seeds, regardless of whether this dispersion is ensured by 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 in highly artificial habitats such as urban environments.

Selecting in favour of exotic and generalist species. Almost all studies examining not only the number but also the type of species present or abundant concur that the selective effect of urbanization density, whatever the context, favours exotic (or neophyte or invasive) species and conversely disadvantages native, archaeophyte[13] 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.

[13] Archaeophytes are species introduced before 1500.

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 fallow land and on paths (ruderal) and those that benefit from nitrogen enrichment of the soil (nitrophils) are favoured, as are plants derived from bulbs or rhizomes (geophytes) due to mowing.

Overall, these studies are broadly validate the selection hypothesis, with generalist species being favoured in most studies, with more mixed results for specialist species. The presence of favourable habitats, such as wastelands or green spaces, tends to favour 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 when these habitats have been preserved in cities. However, the link with agricultural intensification was not taken into account in the analysis. Indeed, in most articles, if agricultural areas are included, their level of intensity of agricultural practices is not specified. In addition to the rate of urbanisation, the size of cities, their age and the 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 not been able to reach a conclusion on the effects of artificialization on plant species. These more ambiguous results are obtained in studies testing the role of artificialization on the whole flora, and not on particular species or habitats. Thus, floristic richness is sometimes adversely affected, and sometimes independent of the rate of urbanisation or other human disturbances. Some studies highlight the greater floristic richness of cities, particularly at average levels of urbanization (as opposed to wildlife). This could be explained by an effect of the **combination of both indigenous and exotic assemblages**, and/or by a positive effect of spatial heterogeneity, in relation to a decoupling of the negative effects of artificialization on specific and functional diversity.

While 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 areas and two series of inventories over time show long-term homogenization effects, particularly due to exotic species, which are found everywhere, but others indicate an absence of effect or partial homogenization (some types of indigenous species in certain cities).

Regarding the hypothesis of the depletion of 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 infrastructures. Similarly, there may be a correlation between the floristic richness and that of certain animal groups in these habitats.

Form of land take	Types of organisms	Effects on biodiversity						Total number of results
		Species richness	Abundance, presence	Select for generalists	Select for specialists	Diversity (genetic, ecosystem, landscape)	Demography	
Poor habitat quality, disturbances	Flora	-0.8	1	0.8	0			12
	Fauna	-0.9	-0.8	0.5	-1			24
Urbanization 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

Figure 3-1. Average index of the effect of land take on fauna and flora biodiversity and total number of results analysed. Each effect is expressed as an index between -1 and +1, depending on whether the effect is negative or positive, equal to 0 if the effect is not demonstrated. 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 richness (0.4; 13) than faunal richness (-0.1; 66), although this is offset by a greater abundance of fauna (0.4; 10).

3.1.4. Effect of land take on animal species and groups of species

Overall, land take 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 biodiversity parameters of animal organisms. 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, as certain larger generalist or domestic species are favoured by urbanisation (red fox for example), however, the opposite is true for large predators (lynx, grey wolf, puma etc.). Conversely, the presence of green spaces is favourable to the presence of mammals in urbanized 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 urbanized areas.

Landscape configuration associated with land-use changes also influences animals. According to the theoretical framework of environmental filters, artificialization on a landscape scale mainly affects small faunal species that have reduced dispersal capacities and are mostly terrestrial. The greater the affinity between an organism and agricultural or forest habitat, the more it 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. beetles unable to fly). 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 effects of fragmentation on fauna but clearly negative effects beyond a certain threshold of artificialization.

Increased interaction between animals. Urbanization and fragmentation of natural habitats also tend to increase the number of interactions between animal species in an unfavourable manner 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 movements due to avoidance of human activities, potentially leading to the co-presence of competing animal species at the same time of day. This urbanization effect of increasing potential faunal interactions is related to habitat loss and the presence of animal species in areas of high human occupancy with domestic animals that pose a danger. The barrier and pathway effects of human infrastructure push animal species to use the same routes along which to travel.

Threshold effects. Some studies demonstrate positive effects of land take or fragmentation of natural habitats up to a certain threshold. 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 mostly negative for very different organisms. Specific 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, namely: 1. that **generalist animal species and exotic and ruderal plant species are favoured by urbanisation,** demonstrating the **'environmental filter' effect**; 2/ that the connectivity of landscapes is favourable to fauna and flora. In contrast, the studies conclude that **the negative effects of artificialization on fauna are greater than on flora, particularly the density of urbanisation to which fauna is more sensitive than flora.**

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

3.1.5. 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 their footprint and traffic. Forest roads 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 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 travel 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 landscaping.

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 conclusion is that animal species are generally less numerous. The disturbance of the original environment by mining operations is significant and of different kinds (logging, 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 be carried out at different rates depending on the species: the animal species present are chronologically linked to the stages of recolonization by plant species.

3.1.6. Conclusion, and strategies to minimise these impacts

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 (wealth, abundance...), and the groups of species on which researchers are focusing their attention. Even for hypotheses that appear to be very solid 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, might 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 the 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 better 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 artificialized areas**, which can increase impacts on biodiversity, and **developing open landscape mosaics**, which are more favourable to biodiversity but require more space.

3.1.7. 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 researchers' different specializations, but 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 an effect on a certain plant or animal species. The participation of the human and social sciences would be highly desirable, in order to consider the perception of biodiversity by various groups (inhabitants, city gardeners, etc...), in order to better guide the recommendations. The production of maps or plans that combine this information (landscapes, effect on organisms, perception by 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, which allows temporal comparisons. Similarly, plant studies concern more varied biogeographical fields, or for some, compare a significant number of cities, on a national or world scale, whereas studies on fauna are often location-specific, and would benefit from being extended geographically in order to compare the effects of land take by strictly applying the same methodologies. The same observation applies to work based on a case study that makes 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 context, bioclimatic factors, 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 estimated from the results of the effects of changes in landscape composition (essentially increases in mineral 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.).

3.2. Impact of land take on urban hydrology and stormwater management

Among the determinants of land take, urbanisation is predominant in the modifications of hydrological functioning, by greatly increasing runoff flows and the resulting risk of flooding[14]. It also affects the quality of run-off water, which is laden with pollutants when it comes into contact with materials (built structures, surface coverings, street furniture, vehicles, etc.) and leaches pollutants from human activities that are deposited on surfaces. 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 a focus of the literature analysis.

The history of runoff management involves several phases. The development of wastewater systems, motivated by sanitation and public health, dates back to the 19th century. To transport wastewater out of the city, urban planners and engineers chose to use the existing storm water drainage network (the so-called unitary network option). Wastewater treatment became widespread in the second half of the 20th century, accompanied by separate, distinct networks for wastewater and stormwater. 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 became clear, such as pollution peaks linked to direct discharges into the natural environment during rainfall events and urban flooding.

An initial response was the creation of centralized rainwater storage and decantation facilities. More recently, the option of controlling rainwater at source, known in France as 'alternative techniques' (to 'piping all'), has emerged. This development marks a turning point in urban water management, by reintroducing the various components of the water cycle, in particular infiltration. At the same time, water in the city is once again becoming an environmental asset, an object of pleasure. Major efforts are devoted to the restoration of urban watercourses. Vegetation, which consumes water, improves the living environment and could limit the urban heat island effect (see 3.3 below).

Box 3-1 – Analysis of the literature

The analysed literature includes 335 references, of which 49 are syntheses. The geographical origin of the collection is as follows: 151 documents from Europe (including France), 66 from the Americas (mainly the USA), 20 from Oceania, 17 from Asia, and one from Africa. The case studies represent 101 documents. The distribution of documents on the different themes is as follows: 132 for the theme 'impacts on the water balance', 66 for the theme 'impacts on rainwater pollution', 92 for the theme 'alternative rainwater management systems', 45 for the theme 'Actors, territories, governance and management'.

3.2.1. Impacts of land take on hydrology

3.2.1.1. 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.) first generates surface runoff, to the detriment of infiltration and evaporation. In the presence of wind, vertical surfaces intercept some precipitation (not quantified). 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 (compaction due to uses and works, presence of embankments, the nature of and organic matter content in the soil, etc.) modifies the structure and texture of the soil (see above 2.1). Thus the temporal and spatial dynamics of infiltration and sub-surface flows are more strongly influenced 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. Leaks from drinking water supply networks are sometimes a significant source of groundwater. The sewerage networks (waste water or rainwater) and the excavations 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, for example). Wastewater seepage to the ground also occurs (estimated at an annual water depth of 10 mm in Nottingham). The presence of pumping to feed urban activities and lowering the water table in the vicinity of underground infrastructures (car parks in particular) affects the level of underground water tables.

[14] This ESCo does not deal with the question of the vulnerability of buildings situated in flood zones with respect to river floods or coastal floods whose determinism goes far beyond the question of the artificialisation of soils, and which are already strongly constrained by existing regulations.

• Watershed Impacts

Watersheds affected by urbanization present a great diversity of situations, from partially urbanized watersheds or watersheds in the process of urbanization (peri-urban) to watersheds that are totally urbanized and equipped with a rainwater drainage network. A catchment area is often characterized by a runoff coefficient defined by the proportion of rain that turns into flow at the outlet during a rain event. During common rain events, this coefficient is often significantly lower than the proportion of waterproofed surfaces. Its value increases with the importance of rain events, sometimes exceeding the waterproofing coefficient.

The influence of urbanization on the hydrological regime of **small rivers** should theoretically translate, in an urbanized or urbanizing watershed, into an increase in flood flows and mean flows, and a decrease in low water flows. Observations in the field lead to less clear conclusions, or even different conclusions for average flows and low-water flows, which emphasise that 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 **surface 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 lead us to consider these results with caution.

Land take also affects **evapotranspiration**, which is now an issue in urban areas because of its importance in the hydrological and energy balances of urban areas. In urban areas, it is still poorly documented. Its measurement is infrequent, due in particular to methodological difficulties (translation of 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, which must be interpreted within orders of magnitude. These results indicate that evapotranspiration represents an important 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.

3.2.1.2. Impact on stormwater quality

In artificial environments, urban (roadways, concrete, safety equipment, street furniture) or interurban infrastructure (road networks), 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 rainwater runoff.

Special attention is paid in the literature to urban rainfall discharge (RUTP): this term refers to direct discharges to the environment of effluents from unitary networks during very intense rain events that place them in an overload situation. These RUTPs therefore contain the pollutants present in both rainwater and wastewater.

• Sources and pathways of pollutants transfer

Pollutant emissions linked to **automobile traffic** can be due to engine emissions (exhaust gases, loss of fluids on the road), and to vehicle and infrastructure wear (brake pads, tyres, safety barriers or warning signs, catalytic converters, etc.). Traffic is the overwhelming source of polycyclic aromatic hydrocarbon (PAH) emissions and a source of metals (copper, zinc, antimony, lead, platinoids, etc.). Other classes of pollutants are also likely to be released by vehicle materials (phthalates, alkylphenols, and bisphenols).

Among **building** materials, roofs are significant sources of metals (cadmium, copper, lead, zinc), and some PVC elements (gutters) can emit alkylphenols and bisphenol A, but also organotins. Construction timber, facade cladding and green roofs can be sources of biocides, observed, for example, after the construction of urban infrastructure. Contamination of runoff water can occur during maintenance operations on buildings, roads or urban areas (pesticides, fertilizers, snow removal salts). Emission reduction policies for some families of organic pollutants face the challenge of determining their origin, with molecules (e.g. bisphenol A and phthalates) used in a wide range of products.

• Characterization of stormwater runoff

Recent research on stormwater runoff from urban hydrology observatories (URBIS network) confirms the presence of many classes of pollutants (Box 3-2). The transfer of rainwater loaded with pollutants into the networks concentrates, at the outlet of the catchment areas, pollution resulting from the mixing of effluents from various land use zones. However, rainwater contamination with PAH, nonylphenol (NP) and some trace metals can be significant at the parcel scale, with strong variability between rainfall events.

In rainwater, some pollutants are transported mostly by particles (PAHs are more than 90%, lead and chromium more than 80%), 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 runoff as close to the source as possible to treat the dissolved pollution, and not limiting the treatment to decantation. 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 of the facilities also influences the transport; the microorganisms in the facilities are specificity linked to the quality of the water.

Box 3-2 - Data on rainwater contamination from the ANR project 'Innovations for Sustainable Urban Water Management' (INOGEV) (see full report for figures)

The study of three urban catchment areas equipped with separate networks, representing different types of land use (detached housing, residential with apartment buildings and individual housing, and industrial; located respectively in the Paris region, in Nantes and near Lyon), produced new information on the effect of soil artificialization on runoff water quality:

- Little or no documented metal concentrations from buildings, roads and human activities (arsenic, cobalt, molybdenum, platinum, strontium, titanium, vanadium) have been quantified. Most concentrations measured in runoff exceed environmental quality standards;
- a difference in the distribution of PAHs between particulate and dissolved fractions, depending on their molecular weight, was found, with more heavy molecules less degradable on the particles;
- Many pesticides are still detected in rainwater, despite the reduction in their use for the maintenance of public spaces;
- The first experimental data on PBDE (polybrominated diphenyl ether) levels in rainwater were obtained: BDE-209 is still present at levels well above those of atmospheric deposition, although significant differences are noted between the different sites. PBDEs are associated with particulate matter;
- Substances (bisphenol A and alkylphenols) are present mainly in a dissolved form, and are therefore mobile.

• Impacts of stormwater discharges on aquatic environments

The impacts of traditional pollutants (suspended solids (SS), nitrogen and phosphorus) brought about by rainwater discharges or RUTPs have been studied for many years. Discharges of suspended solids can have direct clogging effects on the riverbed; oxidation of suspended solids leads to a decrease in dissolved oxygen concentration in the water, which can in some cases lead to fish mortality. Suspended solids are also 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 rainwater discharges. On an event-driven scale, rainwater 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 (when wastewater treatment plants are overloaded in a unitary network). Annually, in the case of alkylphenols and bisphenol A, an assessment in Ile-de-France suggests that rainwater could contribute to between 20 and 60% of pollutant flows in the Seine. Variability is related to rain events.

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 certain organisms (diseases, lower life-span, impaired reproduction), or eventually lead to the disappearance of certain species and thus disrupt the ecosystem. The many organic micropollutants studied more recently in rainwater have consequences on aquatic environments that are still poorly documented.

Finally, rainwater discharges and especially RUTPs have significant **health impacts**. High concentrations of faecal contamination pathogens, bacteria and viruses from animal waste in public areas and by-passed unitary network waste water can lead to the temporary closure of bathing areas or prohibition of other aquatic activities.

3.2.2. Alternative stormwater management systems

In contrast to the rapid drainage of rainwater, which has long dominated stormwater treatment, new approaches have developed over the last twenty years. The objective is to ensure that urbanization disrupts the water cycle as little as possible, including minimizing surface runoff. In France, these are 'alternative techniques' (related to the rainwater drainage network) or 'compensatory solutions' (related to the effects of urbanisation). They are evolving towards devices integrated into urban designs, helping to re-permeabilise the city and restore nature's place in the city. The management of rainwater at its source thus corresponds to a new vision of water as a resource and constitutes one of the main tools for controlling the hydrological impacts of land take.

3.2.2.1. The various available measures

Centralised works, supplied by pipeline networks, comprise underground retention basins in the city centre and open-air basins in peri-urban areas. Most of these devices rely on the decantation of water.

Management techniques at the source rely on the storage and infiltration of rainwater, captured as close as possible to the source, to reduce runoff flows but also the associated pollutant flows. Different devices are being developed (Figure 3-3): 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 parking lots or sidewalks), biofilters (planted filters), etc.

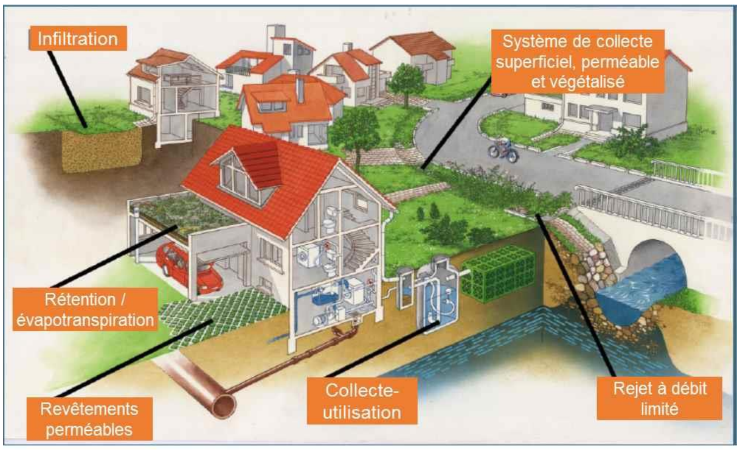


Figure 3-3. Gestion à la source des eaux pluviales (adaptée de Bayerisches Landesamt für Umwelt)

3.2.2.2. Hydrological performance of management systems at the source

At the local scale, the hydrological performances of the various devices have been the subject of numerous studies, often devoted to the observation of their functioning. Most of the structures aim 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 rains. Performance is assessed based on the peak flow reduction or delay, volume reduction, or retention capacity. There is consensus on the effectiveness of the devices, although there is considerable variability in performance. The maintenance of their performances over time depends on the infiltration capacity of the underlying soil layer, and on the maintenance of the structures.

At a broader scale (catchment, urban river, groundwater), 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 in reality. 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 capacity. Knowledge has, however, increased and recommendations have been made to reduce the risk of clogging, and vegetation can contribute to 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.

3.2.2.3. The environmental performance of the various systems

Les dispositifs de gestion des eaux pluviales permettant de lutter contre l'impact polluant des eaux pluviales urbaines dépendent de leur niveau d'insertion (amont ou aval) dans le système de gestion des eaux.

Centralized downstream structures allow efficient removal of particulate contaminants and reduction of metal bioavailability (through interaction with sediments). The use of extensive centralized filtration works (planted filters) is beginning to develop in France. However, 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 in particulate form. However, there is the question 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, adapted to its potential for contamination. They contribute in different ways to the control of pollutant flows. The reduction in pollutant flow is helped by the fact that the leaching and entrainment effects of particles are lower on upstream surfaces (lower flow). Permeable surface coatings show an abatement capacity for suspended matter concentrations, and limit PAH inputs. Vegetated permeable surfaces allow pre-treatment of surface runoff by decantation and filtration through plants. The infiltration of normal rainfall into permeable and vegetated retention structures considerably reduces the annual pollutant flow: these structures (bio retention, rain gardens) ensure the physical filtration of particulate pollutants through the filtering substrate and the sorption of dissolved pollutants, and they are generally effective in retaining suspended solids and particulate pollutants (metals, PAHs). However, the potential for pollutant transfer in the near subsoil of infiltration structures must not be ruled out.

3.2.2.4. The multifunctionality of management systems and the evolution of stormwater regulation

These management systems at the source form part of current urban developments, and designers assign several functions to them: reintroduction of nature or natural features into the city, integration into green and blue networks, structuring of space and greening of neighbourhoods, parking spaces etc. Water basins, but also permeable and vegetated structures (by promoting water storage in surface layers that make it available for evaporation, which cools the air) could also contribute to limiting the urban heat island. Finally, the vegetation associated with these devices participates in the conservation or development of biodiversity in the city.

These technical developments mark the transition from the technical sewerage network to an **urban water management system** as defined by the General Local Authorities Code, which includes technical measures but also contributes to urban development and quality of life. The services and stakeholders involved (designers, managers, users, etc.) in the operation of this system are more numerous. The multifunctionality of structures and multi-stakeholder interaction require new approaches and entail an evolution in stormwater governance (Box 3-3).

3.2.3. Limitations of current studies and identification of research needs

3.2.3.1 Limitations of current studies and identification of research needs

Urban hydrology is defined as the science of the water cycle in an urbanized 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 always 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 rainwater management techniques, protection of aquatic environments. The participation of water and vegetation in 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. In urban hydrology, as in all environmental sciences, in situ and long-term monitoring represents a basis for research, a basis for collaboration between teams and one of the keys to the success of interdisciplinary projects. The creation of urban hydrology monitoring was initiated with the creation of the URBIS Observation and Experimentation System for Environmental Research. It is important to continue and strengthen this initiative (e.g. SNO, SOERE) which must naturally include the monitoring 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 patterns. These include water flows in the soil and near-soil, the soil-atmosphere interface etc. 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: i) design and size of source management systems, ii) integrated modelling of urbanized and peri-urban catchment areas, iii) combined modelling of water, pollutant and energy transfers in urbanized environments.

Strengthening interdisciplinary research approaches to the urban water cycle. All of the functions of urban water management systems can only be studied within the framework of interdisciplinary projects that bring together different components: 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 schemes.

Box 3-3 - Stakeholders, governance and management

Control systems at the source of stormwater contribute to stormwater management and are an integral component of urban projects. This evolution in practices raises new questions in terms of local policies, actors, territories, governance and management of public services.

Public policy: a partial acknowledgement of different issues

In 1992, stormwater was recognized as an area of public policy by the legislature, which decided to regulate 'rainwater and runoff' through unitary and separate systems.

The analysis of local policies in this field underlines the presence of a profusion of stakeholders and territories. It was only after the recent decree of 21 July 2015 on the management of water flows in rainy periods in a unitary system that prompted greater cooperation between public sanitation and urban stormwater management services (entrusted to municipalities since the reform of the territorial organisation in 2014). Sanitation will become the responsibility of intermunicipalities by 2020. Therefore, further details will need to be clarified and the conditions for exercising and transferring responsibilities (inventory of assets, assessment of loads, rainwater management, etc.) will be shared in the near future.

For territorial stormwater management policies, there seems to be a clear preference for regulatory instruments to integrate stormwater into development as far upstream as possible. The requirements established by local authorities lead to an adjustment of urban projects. Local authorities ensure that their regulations are met.

The questions posed by climate change remain poorly addressed by managers and remain research concerns. The issue of pollutants is also poorly represented in local policies due, among other things, to its diffuse nature.

What systems, what assets, at what cost, and for what services?

The transition from the 'one pipe' solution to management at source introduces the concept of an urban water management system (UWMS) which groups together the different infrastructure (linear and surface), the natural or urban watershed(s), the organisation, i.e. the management service(s), but also the natural and human environment. The UWMS marks the evolution of the purely technical sewerage network towards a system that includes technical devices, but also contributes to urban development and quality of life. This management at the source of stormwater extends to effectively providing ecosystem services in urban areas. The multifunctionality of structures and the multi-stakeholder interaction require new approaches.

Asset management involves an inventory and identification phase for the various devices (including in particular vegetated devices), which raises the question of access to data and the definition of a common typology. A new field of investigation has been added, that of positive externalities linked to the aesthetic, landscape and recreational aspects. Asset management is based, on the one hand, on the maintenance of equipment during its life cycle and, on the other hand, on its rehabilitation or renewal. There has not yet the hindsight to predict the condition of these devices over time. There are also questions about the financing (general budget, supplementary budget for sanitation, private ownership etc.) and the depreciation period, as well as the person or persons responsible for the maintenance and/or rehabilitation of the systems.

3.2.4. Conclusions

For many years, qualitative urban hydrology has shown the strong influence of soil sealing and the presence of underground networks and structures on the local and wider-scale water cycle in urbanized areas. Artificialized soils, except sealed surfaces, can also have, on a local scale, an impact on water availability for vegetation due to compaction phenomena 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 (transport, heating, industrial emissions, etc.) and deposited on surfaces.

The proposed policy instruments are based on the 1992 legislation on the regulation of 'rainwater and runoff' by unitary and separate systems and aim at the development of centralized structures and management systems at the source. They are part of current multifunctional urban developments: reintroduction of nature into the city, insertion into green and blue spaces, organization of space and greening of neighbourhoods, parking areas, conservation of or promoting greater biodiversity etc. Water basins, but also permeable and vegetated structures, could also contribute to limiting the urban heat island. Integrated urban water management reinforces the crucial role of the water cycle in urban projects and creates new perspectives with increased needs in terms of monitoring and integrated models. Asset management of structures and facilities is also a new field of investigation for research, based on studying the role of the stakeholders involved in design, maintenance and even rehabilitation, with the aim of helping local authorities review their organisational structures.

3.3. Impacts of artificialization on the physical urban environment

The consequences of artificialization on the urban microclimate, on the acoustic environment and on air quality will be examined here, although these depend mainly on the 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 and also the feedback from these climate changes on the local level, as well as many other impacts (air pollution, economy...). It would also require the development of approaches to the urban metabolism[15] 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 by the uses it permits or encourages. The processes involved and their impacts are studied on the one hand at the scale of the simple surfaces, and on the other hand, from the scale of the buildings or the street to the scale of the city (district, city, agglomeration). Changes in surface conditions, sprawl, and densification processes will be addressed in terms of their impact on thermal and acoustic amenity within cities.

Box 3-4 - The Sky view factor approach to artificialization

The 'sky view factor' is an approach widely used by researchers working on radiation trapping in cities. It describes the effect of urban form on the urban heat island effect. This factor is defined as the proportion of the sky (hemisphere) seen by the observer, and thus not obscured by any physical objects. This parameter essentially measures the exposure of the urban fabric to the sky. This approach is based on a 3D model of the city. This 3D model is also considered in the calculations of the developed surface, which integrates the vertical dimension of the city and involves adding all the vertical surfaces of buildings to the horizontal surfaces, the aim being to be able to calculate heat exchanges (Table 3-1).

District	**Building footprint** (building surface / ground surface of the district)	**Building frontage** (frontal area / developed area of the district)	**Density of building surfaces** (built envelope area / developed area of the district)
Douve (detached housing)	18.5	19.1	34.1
Baugerie (low-density collective housing)	18	25.2	38.7
La Télindière (individual housing in rows)	21.8	31.7	46.6
Graslin (old town centre)	62	57	83.7

Table 3-1. Proportions of different surfaces types in the surface model developed for several districts in Nantes

3.3.1. Impacts on the urban microclimate

Cities are characterized by a specific microclimate due to the nature of urban surfaces (mainly mineral), the shape of the city and human activities (heat emissions...). The specific nature of the urban microclimate is expressed mainly by the **urban heat island** phenomenon (higher temperatures in the city than in neighbouring rural areas). In addition to its negative impact on comfort in urban areas, the ICU phenomenon raises health issues with sometimes dramatic consequences, such as during the heat wave in the summer of 2003, which resulted in an estimated 70,000 more 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 parameter measurement programs describing the microclimate, but there do not yet appear to be sufficient studies.

Box 3-5 – Analysis of the literature

The analysed literature includes 524 references, including 52 books and 392 articles from international journals. The geographical origin of the studies is highly variable and includes applications in Asia, Europe, the Americas and in lesser numbers on the African continent.
Broadly speaking, the current studies focus on three scales:
- The city', where the urban heat island is studied, its formation with the densification and spreading of cities, and its relationship with the spatial characteristics of the city;
- That of the district, selected to analyse the thermal comfort as a function of urban design and development;
- The highly-localised surface area, where the effectiveness of the cooling systems is evaluated.

[15] *Urban metabolism can be defined as all the transformations and flows of matter and energy involved in the life cycle of an urban area (Bochet and Cunha, 2003).*

3.3.1.1. Principles for studying urban climates

• Urban microclimate description; vertical range

The troposphere is a set of **atmospheric layers**, of which only the Atmospheric Boundary Layer (ALL), known as the Urban Boundary Layer (UBL) above cities - 500 m to 2 km thick - will be influenced by humans. The latter is broken down into: a mixing layer and a surface layer that includes the urban canopy corresponding to the irregular urban elements, from the ground to the average roof level.

• Physical phenomena influencing the urban microclimate

The urban climate results from energy exchanges (radiative, thermal) and water exchanges between surfaces and the atmosphere, and from aerodynamic interactions between the canopy and the atmosphere which occur at very different time and space scales within the CLU.

The water balance (Figure 3-4.A) reflects the exchange of water between the soil and its underground networks, surfaces and the atmosphere during rainy or dry weather, and takes into account the spatial variability of the soil surface characteristics (impermeability, presence of vegetation), the hydrodynamic properties of the soils (permeability) and the presence of underground networks that constitute preferential drainage sites in the soil. The evapotranspiration flux between surface and atmosphere corresponds to a heat flux, the latent heat flux (cf. 3.2).

The energy balance (Figure 3-4.B) represents the balance between the net radiation, the latent heat flux (from the water balance), the perceptible heat flux (convection at surface level) and the heat flux stored by conduction in the ground and throughout building shells.

Aerodynamic interactions between the canopy and atmosphere result from aeraulic phenomena, i.e. processes that describe air flows (Figure 3-4.C).

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

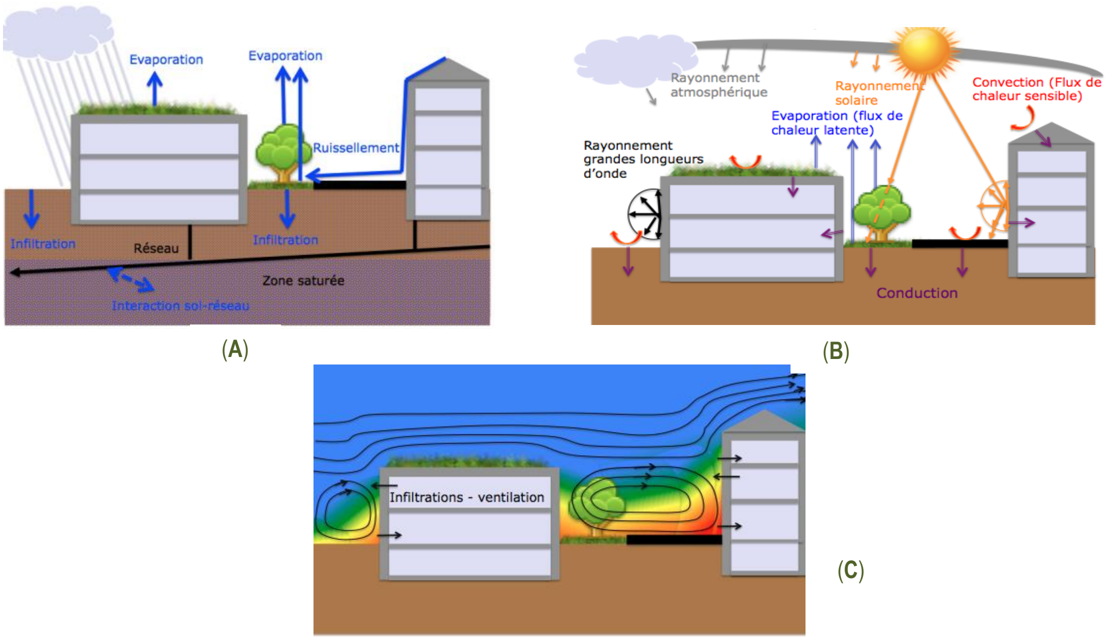


Figure 3-4. Water balance (**A**), thermo-radiative balance (**B**), and aeraulic processes

3.3.1.2. 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.

• Urban heat island measurement methods and data analysis

Surface temperatures in urban areas are mostly measured by **remote sensing**. To characterize **atmospheric ICU, *in situ*** measurements are used, typically using sensors placed in the urban canopy layer (Figure 3-4.c) that record air temperature, humidity, wind speed and direction, and heat flux.

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 a few explanatory variables identified by considering the phenomena involved (population, urban form, land use etc.), or with geoclimatic classification methods, which aim to identify climate-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 urban heat island** and the **development of urbanization** by analysing historical datasets.

• Climate modelling approaches for the urban heat island

The last decade has seen important 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 ICU phenomenon. Urban climate models can be classified into two classes, 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 environment' approaches) aim to study the heterogeneity of the physical environment 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, floors, 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 specificities of the urban environment having an influence on 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 main 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, leading to the phenomenon of ICU in contrast with the air temperature of less urbanized areas. The spatial pattern of the ICU 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 (threshold above which one estimates having a signature of urbanization) is much more extensive in cold seasons than in warmer seasons. In contrast, the maximum intensity of ICU appears to be less season-dependent.

Studies are in agreement that the greenest neighbourhoods have lower surface temperatures than more built-up neighbourhoods. In Marseille, this was used to identify eight types of urban districts, each characterized by an average temperature and a standard deviation reflecting the heterogeneity and combination of the characteristic areas 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 air heating are roofs, streets and paved floors exposed to the sun, and streets covered with asphalt and roofs reach the highest temperatures; exterior walls and trees have the highest night temperatures; open spaces, exposed to direct sunlight during the day and to exchange with the night sky, have the greatest daily temperature variations. The contribution to ICU increases for the following surfaces in order: grass, bare soil, paving, concrete, 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 make models by combining climate change scenarios with or without urban development. A prospective study (Agüeso, 2014) thus shows that the increase in night temperature linked to urbanisation could be twice as great as that linked to climate change by 2050. On the other hand, urbanization seems to have little impact on maximum temperatures.

3.3.1.3. Solutions to mitigate the impacts of urbanization

The solutions proposed in the literature are aimed at influencing the nature and properties of the 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 as they are now considered as additional surfaces (usable for installing solar panels, gardens, etc.) have been the most studied.

- **Grey solutions (for building materials)**

Research to **increase the albedo of surfaces** is highly developed. This is achieved by using light-coloured and 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** are advantageous in ensuring summer comfort in buildings. However, they have the disadvantage of returning solar fluxes that are not absorbed to the surrounding surfaces (source of inconvenience).

For **pavements**, **light-coloured** coatings are particularly interesting compared to conventional pavements that absorb solar energy. The other option explored is the search for **evaporative pavements**, which heat less due to the consumption of a portion of the solar energy by water evaporation. The first solution consists of watering the pavements (impermeable) during hot periods. The second is to retain rain and runoff water in a porous coating. A recent statement of current knowledge (2015) on 'cool surfaces 'concludes that their real influence on air temperature is not well known; their impact on the thermal behaviour of adjacent buildings and on pedestrian comfort has been scarcely addressed. Their validation therefore remains necessary. Surface coatings have also undergone technological innovations in recent years to give them multifunctionality. Photovoltaic pavements, for example, in addition to producing electricity that can be used for lighting, make it possible to reduce the surface temperature compared with conventional pavements; a first experimental section has been installed on a road in Orne.

	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	
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 facades	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

Table 3-2. Key technical solutions at the local level to mitigate the urban heat island

At the scale of the urban area, only 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 an actual 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 (often in the order of only a degree Celsius) strongly depends on the type of surface modified (ground, walls, roof), 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 interesting than their greening.

In the realm of reflective materials, current work is focused on optimizing the distribution of the optical characteristics of materials in the streets, necessary to avoid acute conditions of discomfort. Moreover, in temperate climates, the use of these surfaces may increase the energy consumption of buildings in winter.

- **Green solutions (urban greening)**

Green solutions have been by far the most studied, at least on the scale of surfaces. Vegetation can affect 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, shade (for wooded surfaces) and evaporation/evapotranspiration favoured by water retention. The improvement in comfort in summer will be noticeable during the day under trees; on the other hand, open grassed surfaces generate coolness at night but have little impact during the day.

Green roofs have proven effects in cooling the interior and limiting the heating of external temperatures near the roof. The thermal effect at ground level remains low; it varies according to the characteristics of the plant roof (substrate, foliage density, etc.) and the building (height, insulation, etc.), and according to the type of climate. The interest of green roofs is thus decreasing for hot and dry, hot and humid, and 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) with lower temperature rises. They thus improve comfort during the day. Effects on street air temperature depend on climate, containment effect (street shape ratio) and water availability. Green facades keep the air cooler in streets where the confinement effect is high (high height/width ratio).

The major conclusion is that heavily vegetated sites remain cooler than heavily built areas. **Green spaces** create more comfortable zones locally during the day and at night, but they can also contribute to the cooling of nearby neighbourhoods (Figure 3-7), depending on prevailing winds and the morphology of the neighbourhood (streets more or less open to the park).

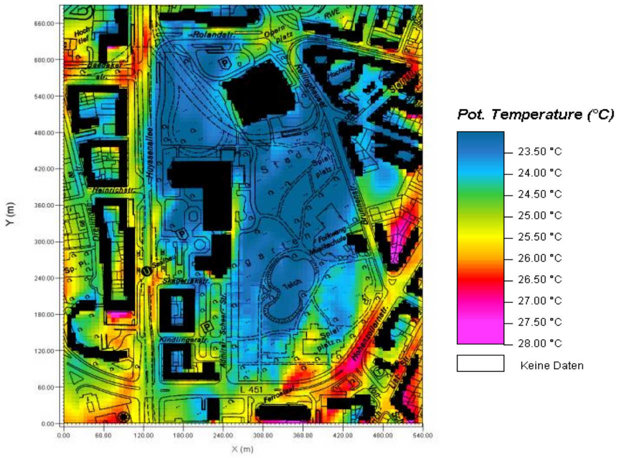


Figure 3-7. Air temperature (°C) in and around an urban park in Essen (Germany). Map obtained with the ENVI-met model (Lahme and Bruse, 2003)

- **Blue solutions (water based)**

Depending on their size, **standing bodies of water** can have a positive or negative impact on the ICU. 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 constantly. Some studies conclude that there is almost no effect, while others conclude that there is a significant effect, so it is very likely that the relationship between the effect of watercourses and urban morphology, which is little investigated, is a major determinant of the climatic effect of watercourses on the surrounding neighbourhoods, as is riverbank development.

Also worthy of note is the development of basin roofs (blue roofs) that store rainwater to relieve water network congestion. Their effect on the ICU has been little studied, but we can believe that it will be similar to that of watered surfaces, and lower than that of green roofs which develop a higher evaporation surface. In addition, they pose health and maintenance problems linked to water stagnation. The proposed solution is to cover them with a porous material.

- **Solutions based on urban design**

In arid climatic zones, high buildings and streets mainly oriented north-south make it possible to minimize the number of hours of thermal discomfort; and to structure the city in blocks made up of interior courtyards is preferable to structures of the 'canyon street' type or 'large complexes'. These conclusions, acquired in particular urban contexts, cannot however 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.

3.3.1.4. Current Gaps and Opportunities

- **Improved models for the evaluation of ICU reduction techniques**

The objective of evaluating alternative urban planning techniques to reduce ICU 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 for improvement remain.

With regard to soils, 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 considered to regulate urban climate, coordinated work with urban hydrologists is needed to better represent, in climate models, the interactions between vegetation, surface, soil and subsoil.

Concerning 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 (climate, urban morphology and building type) makes analysis difficult. Exploring a wider range of solutions requires taking into account building / urban climate interactions, and therefore developing tools to represent both the building physics and the microclimate.

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

- **Modelling at a city scale**

Very little research has been done on assessment methods necessary to develop urban strategies to better cool the city. The difficulty is that there is no universal solution, and the effects of the 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 be able to forecast the need for 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 able to describe urban morphology in detail. Thus, solar trapping and ventilation at a city scale are poorly treated, in relation to the urban form, materials and nature of the soil.

3.3.2. Land Take and air pollution

To our knowledge, no scientific work has been conducted on the relationship between land take (or urbanisation) and its effects on air pollution. Many studies analyse pollutant emissions and concentrations and their trends in cities, or show the impact of the development of large urban areas 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.

Box - Analysis of the literature

The scientific literature relating to air pollution is very broad, with an abundance of highly specialized literature on the modelling, observation, analysis, and effects of air pollution, but significant knowledge gaps, depending on the pollutants, processes, causal activities, and effects. The analysis contains approximately thirty references. Among these, 6 implement physico-chemical modelling chains (although none cover the full range of links from activity to effects on populations) and consider particulate pollution or ozone, based on case studies with some urban development scenarios. Four other references deal with traffic and emissions simulation. Three studies of particulate pollution are based on the analysis of observations (satellite or ground-based). These studies focus mainly on areas in the USA, China and Europe.

3.3.2.1. Origin and variability of air pollution

- **Air pollution processes**

The processes governing air pollution are multiple and complex (Figure 3-8), with local biogenic and anthropogenic emissions (different areas of activity, transport, energy, etc.) of hundreds of particulate or gaseous pollutant compounds and pollutant inputs from neighbouring or distant territories. 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, resorption by dry or wet deposition etc. Thus land take (change in land use and urbanisation) cannot linked to its effects on air quality in a simple manner.

The effects of air pollution are themselves numerous: they affect, directly or indirectly, human and animal populations, flora, natural environments, the living environment, buildings etc.. To date, there has been 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 into 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 little documented in the analysed literature, probably because they are considered of lesser importance compared to the health effects on populations.

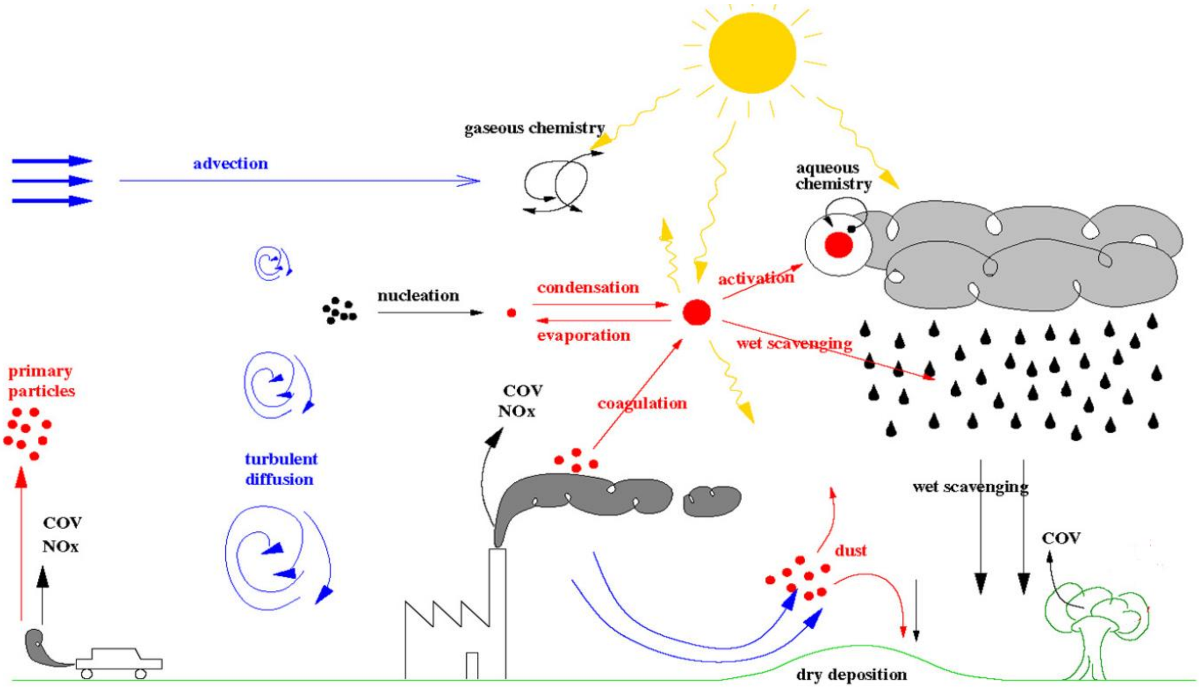


Figure 3-8. Schematic view of air pollution processes (Sartelet, 2017)

- **Spatial variability and air pollution parameters**

Air pollution particularly affects large urban areas, with significant 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 with the geographical (topography, altitude, climate) and meteorological (wind speeds and directions, precipitation, temperatures) contexts, the types 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.

Pollution processes occur at different scales. In simplified terms, a distinction is made between local pollution, which is close to the sources (up to a few tens to hundreds of metres and a few tens of minutes) and thus affects residents and road users, and background pollution, which can spread over several tens to hundreds of kilometres, over several hours or days, and which concerns entire urban areas and beyond.

- **Trends in air pollution**

In France, anthropogenic pollutant emissions are decreasing due to the implementation of regulations and depollution 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 NO2 and PM10), while ozone pollution is on the rise.

This encouraging trend in pollutant emissions and concentrations is not occurring everywhere in the world, and regions that are experiencing strong growth are seeing their pollutant emissions increase considerably, despite rapid progress in implementing cleaner regulations and technologies. Thus, on a global scale, anthropogenic emissions of NO_X and PM10 are still growing at a rate of 1 to 3% per year.

3.3.2.2. 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 to human exposure. The simulations cover different urban development scenarios or the redeployment of populations and activities; the simulations concern pollution episodes (a few days) or an entire year, and concern a given agglomeration or region (with the availability of local data). 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 is strongly dependent on the specific context, but generally it increases with urbanisation, with a relative increase in activity linked to the population, with an increase in mobility possibly aggravated by geographical extension, and consequently with an increase in anthropogenic emissions and concentrations of certain pollutants in and around urbanised areas. Urbanization also increases the numbers of people exposed to these concentrations, which makes it possible to forecast a negative impact on the health of populations. These effects may decrease with the advent of cleaner technologies and regulations to limit emissions and monitor concentrations, although this may be offset by the emergence of new polluting substances, changes in uses and increased population sensitivity, particularly as a result of both ageing and climate change.

- **Relative influence of land use on anthropogenic emissions and exposure**

The main parameters of increased pollution are the increase in anthropogenic emissions, the level of background pollution concentrations and the number of people exposed, urban sprawl and increased mobility. Less important parameters include changes in land use (urbanisation at the expense of forests, grasslands, bare soils or brownfields), possible reductions in natural emissions (negligible compared to anthropogenic emissions), and changes in local weather conditions linked to urbanisation. The same applies to the configuration of neighbourhoods, streets and buildings. Urbanization modifies local meteorological parameters, which in turn influence air pollution in highly variable ways, with increases or decreases depending on the specific parameters.

Research on materials, screens or barriers and equipment that may temper or influence the effects of air pollution has not been analysed here. Their scope is highly localized and only deals with local pollution. Absorbent materials probably have very limited impact in the open atmosphere.

- **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 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. The low density extension (of the current peri-urban type, or urban sprawl) worsens the overall effects (increase in emissions of the pollutants PM10, ozone), however with areas of lower pollution and the dilution of certain impacts (PM10) 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. It also promotes environmentally friendly and active modes of transport and improves the quality of life. Urban morphology and neighbourhood configuration can also contribute to reducing air pollution (lower temperature, better ventilation), although the potential is probably quite limited.

Finally, transport infrastructure, which is implicitly included in the research analysed in urban areas, obviously also contributes to air pollution in non-urban areas. However, the quantities of emissions are much lower than those recorded in urban areas, pollution reduction is more efficient and the affected population is smaller.

3.3.2.3. State of scientific knowledge, research needs, and policy tools

The discussion of the influence of land take on air pollution, and the literature review, have shown that many important issues, which should be developed, are little studied. We note the following: there is a lack of scientific literature (or it needs to be more accessible) on some aspects of air pollution, there is a lack of quantification elements or orders of magnitude that would make it possible to consider the predominant effects, and much of the work is limited (some pollutants, some mechanisms). More generally, more synthesis is needed to allow a more comprehensive understanding of air pollution (from land use to concentrations, exposure and effects on populations), and to take advantage of the many experiments, simulations, case studies, scenarios and other 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 in typical contexts) in order to broaden the analyses and document the effects under different scenarios. This would particularly involve 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 the 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, which also improves the living environment and encourages the practice of environmentally friendly and active modes of transport,
- The development of eco-neighbourhoods, and modes of transport that are eco-friendly, active and public, which would contribute to creating areas of lower pollution.

Even if it is possible to consider 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.

3.3.3. The acoustic effects of land take

Noise is now a major societal problem, as highlighted by opinion surveys among French people living in urban areas who place noise at the top of their list of concerns, along with air pollution and safety concerns. The impact of noise on health is proven: damage to hearing, development of cardiovascular problems, stress, insomnia etc. In order to raise awareness and combat noise pollution, the European Framework Directive 2002/49/EC and the Noise Act No 92-1444 of 31 December 1992 encourage the prevention, reduction and limitation of noise pollution.

Land take results both in a change in the sound sources present (linked to the changes in land use) and in a change in the physical conditions for sound propagation. The latter are affected by direct effects of artificialization, on the nature, properties and arrangement of surfaces, and by indirect effects, via micro-meteorological fields (refraction and atmospheric turbulence effects). These effects can be observed at different spatial scales (street, neighbourhood, city, agglomeration, territory).

Box - Analysis of the literature

The societal challenge of noise pollution and the scope of scientific work on this theme are reflected in the wealth of scientific literature, which includes theoretical, statistical, numerical (simulations) or experimental approaches. The analyzed literature includes 416 references, composed mainly of articles from scientific journals. This research mostly originates from European (France, Germany, Italy, England, Netherlands, Belgium, etc.) and American (USA and Canada in particular) research teams.

3.3.3.1. The 'sound chain'

The analysis of the sound 'environment' distinguishes several links in the 'sound chain': emission, propagation, reception and perception (Figure 3-9).

Sources of urban noise (emissions), and artificial zones are the main locations of these sources: transport infrastructure, industry, professional and commercial activities, leisure activities, etc. In rural areas, noise pollution is mainly linked to the development of transport infrastructure and industry (energy in particular).

The propagation of sound in the air is affected by the environment and by the 'boundaries' encountered by the sound wave, which generate phenomena of sound absorption, reflection (interference), scattering (multiple reflections), or refraction (modification of the wave path during penetration into a heterogeneous environment). Boundary effects (reflection, absorption, transmission) occur in contact with 'solid' obstacles (Figure 3-10) and can be complicated in the presence of particular micro-meteorological conditions.

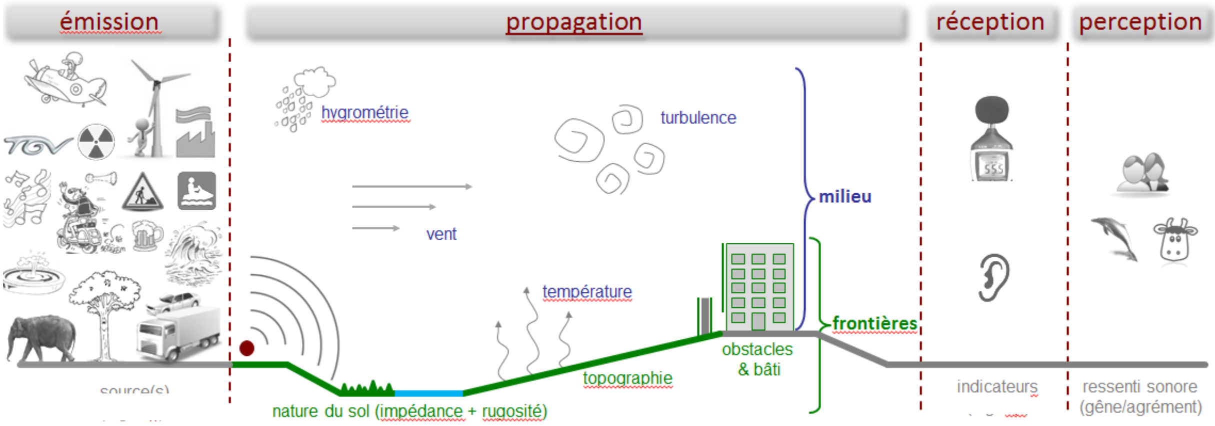


Figure 3-9. The 'sound chain', from emission to reception and perception, via propagation (Source: HDR B. Gauvreau)

While the primary **concern regarding noise pollution involves its effects** is on human populations, the impacts on urban wildlife are also studied through bioacoustics. For example, Dutch researchers have shown that urban titmice, compared to field titmice, increase both the magnitude and frequency of their calls in order to 'cover the noise of human activities'. Human-induced noise pollution in protected areas may also lead to cascading effects on entire ecosystems.

3.3.3.2. Direct effects on sound propagation (boundary effects)

Land take affects acoustic propagation by modifying the nature, and thus the properties, of natural or artificial surfaces, and by multiplying the number of obstructions.

- **Absorption properties and roughness of natural or artificial bare surfaces**

The nature of the surface will determine the degree to which it absorbs sound waves, which depends on parameters such as the porosity of the material. Natural' surfaces often appear more absorbent than modified and especially coated surfaces. The surfaces can be classified according to their acoustic properties, in order from the most absorbent: fresh snow, dry undergrowth, grassland, ploughed earth, to the most reflective: compacted earth, road surface, water, ice, smooth and painted concrete.

Surface roughness also has an effect on sound propagation, which depends on the ratio between the dimension of the roughness and the wavelength of the sound. If the surface irregularity is of the same order of magnitude as the wavelength, the wavelength is reflected in multiple directions. Larger scale surface roughness (topography) can sometimes act as an obstacle and thus mask certain sound sources.

- **Effects of built-up surfaces**

In addition to the physical phenomena linked to the ground (dominant in peri-urban environments), in urban environments (or densely built) other boundary effects are added: influence of urban morphology, obstacles, buildings and congestion, and the diffusion and acoustic absorption properties of coverings, roofs and facades etc. (Figure 3-10).

In urban environments, most sound sources are close by, but the contribution of 'distant' sound sources (e.g., boulevard périphérique) is often significant in the noise environment of a street or neighbourhood.

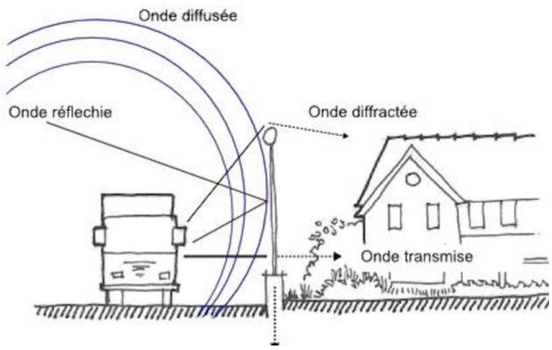


Figure 3-10. Propagation of sound waves in urban environments as a function of the obstacles encountered

- **Effects of vegetation**

Contrary to what residents (or even urban planners) often imagine, a 'linear tree curtain' or 'plant belt' is not an effective means of protection against noise. Beyond its psychosocial-acoustic effect, such structures have limited physical effects on the audible frequencies: a tree curtain absorbs very little acoustic energy, but has the effect of diffusing or diffracting the sound field (in the same way as street furniture), which results in a rapid decrease in sound levels. The sound attenuation effects of a set of trees will mainly be linked to the absorption properties of its soil.

The new greening practices in cities, motivated in particular by the desire to improve the microclimate, have an effect on sound propagation. Acoustic simulations of green building scenarios, as in the ANR VegDUD project (2010-2013), have made it possible to quantify the great disparity in the absorption properties of the various green surfaces, both horizontal (roofs) and vertical (facades).

Box 3-6 - Noise mapping and modelling

At the city scale, the modelling of physical phenomena related to acoustic propagation in urban environments using reference models (TLM, FDTD, PE, BEM etc.) remains challenging due to the considerable computation time involved. This is why it is customary to use simplified models (engineering models), simpler to implement but more limited in terms of possible scenarios, acoustic indicators and accuracy. These acoustic emission and propagation models (CNOSSOS-EU, NMPB2008 tec.), sometimes formalised by guidelines or standards, and integrated into various software tools, now allow numerous studies to be carried out (diagnostic case studies, prospective impact studies).

Figure 3-11. Noise map of the city of Nantes, obtained with the NMPB2008 model and the open source software 'NoiseModelling'

3.3.3.3. Indirect effects on sound propagation (meteorological effects)

The principal micrometeorological effects on acoustic propagation are: refraction of sound (curvature of the sound wave) in accordance with vertical wind speed gradients and temperature, and scattering by atmospheric turbulence.

These thermal and aerodynamic effects on acoustic propagation are relatively well known in unobstructed or 'open' environments. In densely built environments, however, our knowledge of them is more recent, as micro-meteorological fields (wind, temperature, hygrometry, etc.) often present a particularly complex structure, combining vertical and horizontal thermal gradients and changes in wind profiles caused by obstacles. **At street level**, congestion due to the presence of street furniture, parked cars or trees can also significantly alter wind or temperature fields, and consequently sound velocity fields. The effects of thermal gradients in the vicinity of 'classic' walls (stone or masonry façades, concrete flat roofs, etc.) can be clearly limited by the presence of vegetation, which also modifies the sound velocity profiles. **At the urban block or city scale**, wind and temperature profiles within and above the urban canopy can alter acoustic propagation.

The existence and the intensity of these thermo-aerodynamic phenomena essentially depend on the nearby environment (the 'urban roughness'). These local effects, linked to refraction and turbulence in urban environments (or obstructions), are difficult to measure in practice, but have been extensively modelled by linking micrometeorological and acoustic models (the output data of the former serving as input data of the latter).

3.3.3.4. Noise control strategies

There are two main ways of combating noise pollution: at the source of the sound (land use, noise-creating sources) and during its propagation (barriers, obstacles, absorbent coverings, facades and green roofs, etc.). In urban areas these anti-propagation solutions can be combined. Other more innovative solutions have emerged in recent years, which may address very specific problems (stable, continuous and monochromatic sound sources), but they still need to be tested and validated in situ.

3.3.3.5. Current gaps and future prospects

The problem of acoustics in outdoor environments (emission and propagation) is subject to much international research. The advent of ICST (Information and Communication Sciences and Technologies) and in particular GIS (Geographic Information Systems) has created new opportunities in environmental acoustics, in terms of satellite detection, data qualification, and geolocation of sound sources and infrastructure. Noise maps made possible by GIS are of particular interest for quantifying urban areas and populations affected by noise levels. Despite the significant progress made in recent years, many aspects have not yet been grasped, both in terms of understanding and the experimental characterization and numerical modelling of the physical phenomena involved during emission and/or acoustic propagation.

- **Modelling developments**

Models must constantly be adapted to take into account new materials and technologies: for example, innovative pavement coverings, or new generation tyres and electric vehicles for road noise sources.

The **linking of models** (both micrometeorological and acoustic) remains difficult: there are different spatial scales depending on physical phenomena, and calculation costs are too high to allow simulations at the neighbourhood or city scale. Within the framework of the ANR project 'Multidisciplinary assessment and environmental requalification of neighbourhoods' ('EUREQUA', 2012-2017), the principle of a double numerical chaining was tested, involving three models successively: (i) atmospheric fields are first modelled at the territorial/city scale; (ii) these fields are then used as input data at the boundaries of the neighbourhood/street domain, then (iii) the information from the micrometeorological fields is entered into the acoustic propagation model within the street.

- **Changes in the approach to noise perception**

Beyond the narrow and negative concept of 'noise' (noise annoyance or 'nuisance'), the notions of sound pleasure and sound atmosphere have emerged more recently, which are more concerned with perception and feeling (individual or collective). They integrate physiological, psychological and sociological aspects and give rise to the development of new acoustic indicators. The relationship between hearing and other senses is also addressed, as auditory perception appears to be closely linked to the global environment (presence of various sources of nuisance or pleasure, noise or otherwise); its study therefore often requires a holistic approach.

We are also witnessing the development of a **participatory approach**, to which the densely populated urban environment lends itself well, especially since the deployment of smartphones. In recent years, environmental acoustics initiatives have exploded; in France, for example, a smartphone application (NoiseCapture) has been developed in parallel with a website dedicated to urban noise mapping (OnoMap). This, however, should not lead us to forget the metrological and methodological limits (uncertainties linked to the entire measurement chain, spatio-temporal interpolations of data, etc.) of such approaches.

3.3.4 Conclusions

This section on the physical urban environment looks at the relationship between land take and the urban heat island (UHI), noise pollution, and air pollution, which affect thermal, acoustic and air quality levels. 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 affecting the urban environment. Moreover, any increase in urbanization (expansion and/or densification) through increased activities contributes to increasing 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 ICU are more technological in nature, 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 {rivers, 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 noise and air pollution. The interactions between the various tools are complex, however, and can lead to an opposite effect to that initially desired without a broad view of the entire system that encompasses the various parameters involved. 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 (CO2 emissions) and economic aspects (solutions without regret). Research advances point towards the most thorough integration possible, for example by linking micrometeorological and acoustic models, but also by developing urban planning policies that take into account the ICU phenomenon. Data acquisition at local and more general scales remains a challenge to improving maps (temperature, noise, air pollution) and validating models.

4. Agricultural land, agricultural activities, and land take

Land take is 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. The impact of land take on the quantity of agricultural land, agricultural production and the conditions under which agricultural activity is carried out is not always difficult to assess (4.1). It is even less so since the determinants of the land take and/or reduction of agricultural land, which can be examined through the income from agricultural land, are multiple (4.2). The main issue is how to qualify this agricultural area, in a context where it is becoming increasingly difficult to differentiate territories. In a rural or peri-urban area, land take happens on agricultural, forest ou semi-natural areas, the main 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 for the municipality (4.3). This public benefit from the land is preserved by the regulation of uses that can compensate for market failures, particularly with regard to landscape, recreational areas, ecosystem services and natural risk management. Regulation of uses can be achieved through zoning or agricultural policies (4.4).

4.1. Direct impacts of land take on agricultural production

4.1.1. Loss of agricultural land to 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 taking particular account of exchanges between agricultural soils and natural and forest soils, leads to somewhat more nuanced conclusions. The flow diagram for 2006-2014 from the Teruti-Lucas data (Figure 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 soils (+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 soils than between agricultural and artificialized land. Thus, the continuing loss of agricultural land in France combines both a mechanism of loss and gain of agricultural land, probably at the fringes of these productive areas, and a process that is more difficult to reverse in terms of land take.

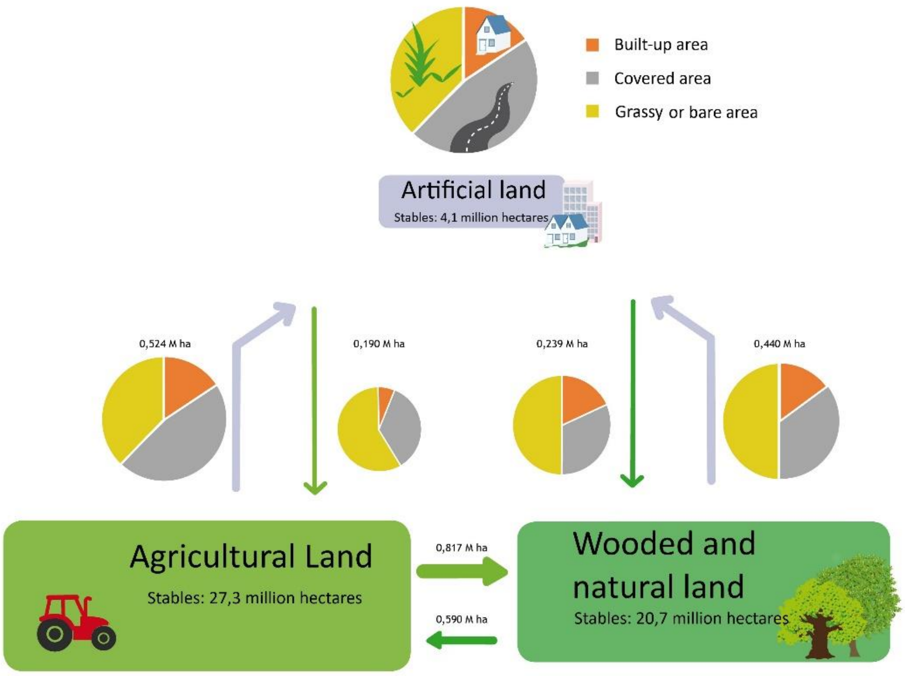


Figure 4-1. Land use change by use from 2006 and 2014. *Source* : Teruti-Lucas, 2014, SSP, MAA. (Graphics: Elodie Carl)

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 land take during the period 2006-2014, half remained grassed or bare and only 15% were 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 nevertheless clear that overall losses of agricultural land are significant, but in order to understand the whole dynamic, it is necessary to consider the processes that lead to their artificialization as well as those 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. On a French scale, land-use changes towards artificialization are a phenomenon which is concentrated in the immediate vicinity of cities and which spread within peri-urban areas. In doing so, and because historically cities have 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 that may already be lacking in local agriculture, natural recreational and/or heritage areas for urban residents, and natural coastal and/or tourist areas that are important from a biodiversity perspective. The issue is therefore not limited to quantities 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 1:1,000,000, and 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 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 public regulation of land use.

4.1.2. From land losses to biomass loss estimates

To estimate the impact of land take on agricultural productive capacities or on production losses in biomass, it is first necessary to know the quality of agricultural soils prior to their use. 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 quality index maps and to 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 multiplied, are unreliable on the scales of vast territories (national or international) due to strong local variations in soil and climate conditions and a strong heterogeneity of agricultural production types and farming 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), Toth (2012) and Aksoy et al. 2017 show 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 of productive capacity between 2000 and 2006 show a loss of 0.26% of total agricultural production in France, which would be in line with the European average of 0.26%, with a per capita equivalent also in line with the European average. A similar study at a finer scale, on 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 offset 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 alienation of agricultural land has been sustained, studies considering this dimension 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 the productive capacities of agriculture 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, taken at the global level, is often exaggerated, especially in Western Europe, and that we are still some distance from the 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 territories caused by the wave of land take, an effect which will be described in more detail later (4.3).

From an economic perspective, land quality is defined for a given use and corresponds to what remains to the owner (private quality) or society (social quality) of the benefits (private or social) once all other factors of production have been met, making 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).

4.2. Income from agricultural land, a driver of land use changes

Any analysis the mechanisms by which agricultural land can undergo a change of use to become artificialized must occur through the lens of income differentials 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 equal to the value of at least three components:

- The value of agricultural or forest land
- The cost of conversion
- The expected future income

Given perfect, complete information, landowners will choose the optimal time to convert their parcel in order to maximize their expected net profit. Neglecting option values, the decision to build takes place when the expected rents for urban use are higher than the agricultural rent 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 buildings, 1.72 €/m² against 95.5 €/m², Box 4-1), it is necessary to question the way in which agricultural land incomes develop and the elements that comprise them, in order to see how they develop 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 actors to convert their agricultural land into building land, although it is not the only factor considered. Policy tools can therefore influence the decisions of public and private actors. The agricultural land rent depends on two main categories of factors: internal agricultural factors, and external factors.

4.2.1. 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, with effects on livestock farmers' choices and on the choices of other perennial crops.

In contrast, the need of fertilizers 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 enlarging the size of fields, bores, or drainage works.

Box 4-1 - The relative effect of quality labels

Quality labels value agricultural activity, but in an equivocal way. Protected geographical indications may strongly impact the price of land, sometimes more than that of biophysical factors. In the Bordeaux region, however, the effect of registered designations of origin is insignificant, which can be explained by an inability to respond sufficiently to urban pressure via a significant increase in land prices.

Finally, with a view to limiting agricultural decline, it is commonly accepted that the stable support for agriculture (CAP, 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.

4.2.2. 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 urbanized areas, and natural areas, must be considered. Also, the effect of SAFERs and local authorities should be examined.

Proximity to urban centres, like road infrastructure, is both a threat and an opportunity for agricultural activities. It can generate new outlets and lead to a specialisation in products with high added value. In this context, local school canteen supply programmes (*farm to school program*) are a significant tool (Box 4-5). The city or the coexistence of competing activities in the same area can be a source of land use conflicts and a hindrance to agricultural activity (fragmentation of agricultural areas by transport infrastructure, restrictions on certain agricultural practices etc.). At the same time, the strong presence of non-agricultural populations can help maintain agricultural activity by providing access to services and jobs. However, this proximity can also translate into land pressure and increase the vulnerability of agricultural land if it does not benefit from 'Protected Agricultural Zone (ZAP)' or 'Protection of Peri-urban Agricultural and Natural Areas (PEAN)' type protection (see below).

Box 4-2 - Impermanence syndrome

Proximity to the city can have negative effects on agriculture by decreasing the time horizon on which farmers' decisions are based. This impermanence syndrome implies that farmers underinvest in their activity, which contributes to diminishing its potential value. Knowing that change of use is rarely reversible and that its outlook is associated with an increase in the value of land, favourable conditions for the emergence of an option value are met. 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.

Natural areas in the vicinity of agricultural land have spillover effects, positive or negative, but generally of lesser magnitude than the above factors. Marginal agricultural land will be more vulnerable to abandonment, but a parcel of agricultural land can benefit from the attributes of neighbouring parcels through externalities such as open spaces or ecosystem services. Scenery and natural habitats positively influence farmland values. Ecosystem services provided by natural areas (lakes, rivers, forests and conservation areas) also benefit the activity. The development of tourism and recreation made possible by natural and forest areas is also a source of extra value for agriculture, which can preserve land from change of use.

In France, environmental protection mechanisms can reduce local land availability, but there is no direct effect on agricultural activity.

Conversely, 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 development. Transaction costs are also included in the price of land, which leads to greater rigidity in the land market, whereby potentially mutually beneficial transactions may not be made. These transaction costs can contribute to distortions in the allocation of land for agriculture.

Box 4-3 - The value of land in France in 2015

According to INSEE's national economic asset accounts, 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 unoccupied agricultural land in the Haut-Jura was 0.14 €/m², compared to 140 €/m² for a Premier Cru Appellation d'Origine Contrôlée vineyard in Burgundy (New series of land prices, 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 €/m² in Limousin to 200 €/m² in Île-de-France (Survey on the price of building land, SOeS).

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

In a peri-urban context, the reasons for abandonment or 'under-utilization' of agricultural land 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. At the local scale, this is a significant phenomenon and can, under certain conditions, form the starting point for land take and urban sprawl, although the cessation of agricultural activity does not mean that the land will be sold or used for another purpose.

As mentioned, **land pressure** in densely populated areas implies an opportunity cost of land occupation that is unfavourable to agricultural occupation. A very detailed study of southern Spain shows that the 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 relative safeguarding 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. However, the process does not appear linear, 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 4-4).

Box 4-4 - Non-linear processes in a peri-urban context: the neighbourhood effect

When land take starts, the fragmentation of farms is very important 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. After a certain amount of artificialization and fragmentation of agricultural holdings, a process of concentration and reduction in the number of holdings begins, which largely 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 and 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 at the origin of a 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 communes 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.

We find a similar dynamic 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 inconvenience, health risks, nature or heritage conservation, etc.). Within this group, conflicts between urban or peri-urban dwellers and farmers are frequent, without being overwhelming; 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 that 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 recent 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 in 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 **resistance of peri-urban farms** in order to identify factors that combat urban sprawl. They show a great diversity of strategies that can be grouped into multipurpose adaptations to the peri-urban context.

It is, for example, 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 family can accelerate the decline 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 then relies on the opening up of commercial opportunities linked to new eating habits of wealthy households. This situation also has the effect of making some small peri-urban farms less dependent on CAP production aid. Peri-urban farms have developed very diverse adaptations to survive, but their common feature is the way they are integrated into the agri-food system, which is based specifically on urban proximity. Some farmers are turning to small crops with very high added value (vineyards), to niche markets, to the economic and social development of the multifunctionality of agriculture or, more often, by expanding direct sales.

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 (Box 4-5).

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 the PLUs, in particular because they indicate local governance organised around an 'agri-urban' agricultural development project, which then translates into a desire 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.

Box 4-5 - The 'Foodshed' concept: the food supply zone

A North American concept, the Foodshed is the geographical area that provides food for a city. If the type of agriculture practised there is sustainable and equitable, local foodsheds provide a great opportunity to strengthen the economics of peri-urban farms, especially since these programmes develop several shared approaches: spatial planning to protect agricultural land close to cities, local public supply outlets, and especially the development of connective infrastructure between the agriculture and the town, such as the opening of markets.

Local school canteen supply programmes (Farm to school programme) are perceived (especially in the USA) as an extension of this phenomenon and a powerful tool. This scheme does not necessarily offer a better income to farmers, but it allows some to avoid cessation of activity by diversifying their commercial strategies.

4.4. Policies to limit the loss of agricultural land through land take

4.4.1. Zoning as a tool to preserve agricultural land

Urban and rural law provide for measures to protect land identified as agricultural land, in order to maintain its agricultural use. These measures may be regarded as effective, but weaknesses in their implementation and the exceptions provided for by the regulations limit their scope. The manner in which the law and public policies may limit land take is developed further, but attention should also be given to the manner in which the law already preserves the supply of agricultural areas.

Environmental law provides protection mechanisms which delimit zones within which land take is limited or even prohibited. In this way, natural areas are protected, and in a stricter manner than the provisions that accompany zoning under urban planning law. Their influence has increased since the 1970s and the protection they provide has increased with increasing numbers of zones.

Zonings related to IUCN categories I to III ensure total protection from construction in the short and long term. They represent 7 of the 200 environmental zones. Moreover, Category IV zoning may ensure the same protection, but the low impact of regional nature parks should be noted. In PACA, for example, 8% of the territory is thus preserved from land take.

The logic of more flexible zoning (which, in the case of PACA, covers an area 5 times larger, with an average of 43% of communal areas), follows a stockpiling principle, whereby the accumulation of these zones makes it possible to build a protection gradient around emblematic areas.

Urban planning law and rural law also use a zoning approach. The allocation of land in zone A (agricultural) in local urban development plans is in itself a form of protection, although this allocation may be jeopardised when the document is renewed. In addition, protected agricultural zones (ZAP) (Article L.112-2 of the Rural Code) and peri-urban agricultural and natural areas (PEAN) protection and development zones (Article L. 113-15 of the Urban Planning Code) are likely to be superimposed on the classification of land in zones A in order to consolidate their use. Created by the legislature in 1999 and 2005 respectively, these two tools are certainly useful, but remain inadequately applied.

The example of the Nantes Saint-Nazaire metropolitan centre should however be highlighted: agricultural land is particularly vulnerable due to low agricultural earnings and, in order to preserve it, the department has set up a PEAN. The PEAN of the three valleys is the most important in France. It covers 17,000 hectares of agricultural land in three communes and acts as a green belt (Box 4-6).

Box 4-6 - Urban growth boundaries (UGB) and greenbelts

'Urban growth boundaries' (cf. chapter 5), define an external limit to the extension of the city for a generally long average duration (10 - 20 years and in the urban area under consideration, urbanisation outside the limits of the UGB is prohibited. Green belts come from a similar concept to that of an area surrounding the city that only allows agricultural use or the maintenance of natural areas. The Dutch model combines policies of preserving open spaces through zoning regulations, and national planning of urban expansion areas, embodied in relatively detailed schemes (Broitman & Koomen, 2015).

Moreover, agricultural zoning does not prevent the artificialization of land within it when it 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 the 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 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 has not dropped, 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). In addition, greenhouses and 'high cover' are recorded as agricultural areas by Teruti and CLC, whereas they most often involve land take.

Finally, in the context of energy transition that sees the development of renewable energy production areas, jurisdictions are increasingly called upon to consider the question of the compatibility of ground-based photovoltaic installations with the use of land for agricultural activity. In response to a need for clarification, a circular from the Ministry of the Environment dated 18 December 2009 stipulated that 'ground-based solar power plant projects are not intended to be installed in agricultural areas, in particular those cultivated or used for breeding herds. Consequently, the installation of a solar power plant on land located in an agricultural zone [...] is generally unsuitable in view of the need to preserve the agricultural purpose of the land concerned. However, solar ground installations may be considered on land which, although located in a classified agricultural zone, has not been used for agricultural purposes in recent times. 'The probable but moderate amount of competition between these two uses remains to be studied'.

4.4.2. Policies to address agricultural production, abandonment and artificialization of agricultural land

Policy to support production plays a key role in slowing the loss of agricultural land. The increases in aid and market prices are **significantly slowing down the rate at which farms are disappearing and slowing down the restructuring of the agricultural sector imposed by market trends**. In order to demonstrate the effect of total or partial liberalisation, several scenarios for the evolution of the PAC were tested, and particular attention was paid to their impact in terms of agricultural abandonment. They predict a limited increase in the decline in the case of partial liberalization (-0.16% of SAU), and more significant increases (-9 to -7% of SAU) in the case of further liberalization of the agricultural sector. The main areas of decline would be in the mountainous regions, particularly on steep slopes, while the valleys and plateaus would be less affected. These areas do not correspond to the areas most threatened by land take (Figure 4-2).

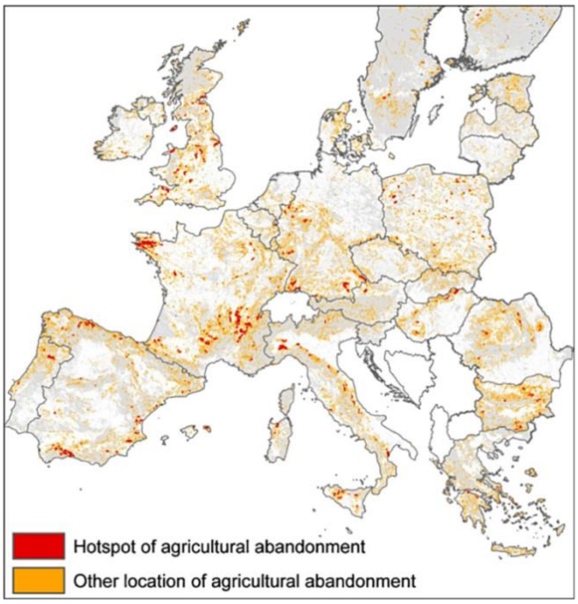


Figure 4-2. Projected areas of agricultural decline under a scenario of liberalisation of agriculture and trade policies within the EU

On the other hand, some critics of the reform of the decoupling of aid and of the cross-compliance of agri-environmental measures put forward the hypothesis that the introduction of better environmental management of agricultural land would lead to land abandonment. Practice shows that this is clearly not the case and these policies cannot reasonably be considered a precondition for land take.

Box 4-7 - Modulation effects specific to certain territorial contexts; mountains

Due to the specific soil and climate characteristics of the mountains, since the beginning of the 19th century 90% of agricultural land has been abandoned in the Alps, 20% in the Prealps and up to 85% in the Pyrenees. Land take in the mountains is variable, but it is clear that the construction of second homes is a strong factor in land take.

The vulnerability of mountain farms is mitigated by diversification strategies that make the nature of the link between their maintenance and the process of land take ambiguous. The development of secondary income, mainly from tourism, is at the heart of this issue. Nevertheless, the trend toward geographically-labelled agriculture (PDO/PGI) strengthens farming, particularly when linked to cheese production (distinguishing it from lowland farming).

In urban and peri-urban contexts, the development of certified farms or their integration into local *foodshed* types of programmes enables them to endure more than others. However, these farms, which are usually market gardening or livestock farms, must make major technical adjustments: conversion to organic farming, construction of direct or local distribution channels, and management of noise and odour nuisances in the event of the presence of livestock near residential areas (management of animal movements and relocation of livestock buildings). A modification of the feeding system is often undertaken with an increase in forage to the detriment of pasture, which can be at odds with the AOP/IGP requirements.

4.5. Conclusions and policy tools

While it is clear that land take can affect agricultural areas, these 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 land-use flows between agricultural and forest and natural land, 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 land take 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 agricultural activities and work. 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.

However, with a view to limiting agricultural land losses in the medium and long term, in order to preserve France's agricultural production capacities and avoid hindering farmers' work, policy instruments exist.

In the first instance, decisions leading to the artificialization of agricultural soils take 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 and 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, while the reversibility of artificial land almost exclusively concerns grassed, bare or simply stabilised soils. 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 may change 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 always seem sufficiently effective in controlling the artificialization of agricultural soils. This raises the question of the appropriate level of governance for agricultural land. Inter-communality may be more appropriate in this case, but with oversight or even reinforcement being maintained at a higher level, such as the Region or the national level. The strategy of strengthening, on the one hand, the land reserve tools and, on the other hand, adjusting taxation on the sale of agricultural land that has become available for construction should be studied further. In the absence of appropriate taxation, or a system for recording agricultural income, as in the Netherlands, a more frequent use of 'deferred development zones' would make it possible to limit the anticipatory effects of developers.

Finally, not all types of agriculture offer the same 'resistance' capacities 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 must 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 tertiary (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** (Figure 5.1), with collective housing representing just 14,000 of the 242,000 artificial surface extensions 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 flow, since only 111,000 of the 242,000 hectares subject to this trend are eventually built on, surfaced or stabilised, while 220,000 of the 243,000 hectares intended for infrastructure or economic activities are sealed. Thus, **the extension of areas for housing results in a mix of surface coverings with varied environmental impacts.**

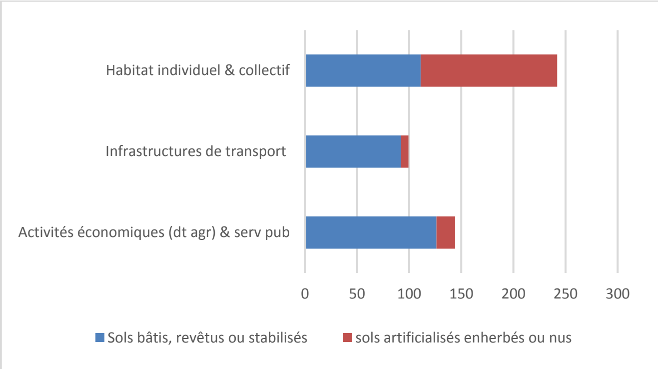


Figure 5-1. Balance of surface coverings within newly-artificialized land 2006-2014 by land use ('000s of hectares). Source: Agreste, 2015

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-urbanization 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 to limit the extension of artificialization both in urban and peri-urban areas, without jeopardizing access to housing and/or hindering the growth of the construction sector.

Box 5-1 - Analysis of the 'Location of households and enterprises' literature

The subject entitled 'Land and real estate dynamics' resulted in the extraction of 1,574 references from the international Econlit, WOS and Scopus databases. Of these, 4 included the term artificializ/s/ation in the title, keywords or abstract (0.25%). In addition to the 164 references used in the analysis to examine the location of households and businesses (which are broken down here between Chapters 5 and 6), 202 new references have been added from additional queries.

The proportion of published studies on France is, as in most cases, quite low, with the United States dominating the study regions. In addition, certain countries or regions have been excluded, such as those in which there is no land market (e.g. China, several African countries) or little land available to further urbanization (e.g. Singapore).

5.1. Housing preferences, urban sprawl and peri-urbanization

Households' residential choices strongly drive urban sprawl and peri-urbanization. However, in parallel with this pattern, the density of areas built at the most general constant urban perimeter appears to be increasing, including in the peri-urban area. Therefore, it would appear that there is 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.

5.1.1. Household location trade-offs: between demand for services, preference for specific location attributes, and socio-economic neighbourhoods

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 city centre. It is through this simple model that we account for the spreading movement of cities around their centre. This is especially true since the proportion of household spending on housing is increasing faster than that on transport, as has been the case for French households for several decades (Box 5-2).

Box 5-2 - 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 increased from 10.6 to 9.8 between 2004 and 2014 (INSEE, National Accounts, 2010 base)..

Children no longer living with their 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 a reduced income, thus fuelling the increase in 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, 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, 56% answered in favour of detached single-family homes, 20% in favour of semi-detached houses, and 11% in favour of small individual dwellings in towns, representing 87% of French people who want individual housing. A move is motivated by access to a garden (23%), an extra room (22%) or a pleasant, unobstructed view (19%). Green areas and landscapes, which are more associated with the peri-urban environment, are clearly popular. 82% of French people place green spaces less than one kilometre from their homes when asked to draw their residential environment. It is also **the lack of large houses or apartments in the hearts of cities** that leads to the preference for suburban areas. There is also a renewed interest in the centre and condominiums in some North American cities such as Toronto.

This movement is accentuated by the conjunction of three complementary phenomena: population growth, with the population of metropolitan France projected by INSEE to rise from 64.5 million in 2015 to around 73.6 million in 2060, an increase of around nine million inhabitants (+14%); the decrease in household size (Box 5-2) which automatically leads to an increase in housing demand and, the preference expressed by households (especially French households) for individual housing (Box 5-2), 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 (Box 5-6), 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 spaces is not linear. In all industrialized countries, the latter is faster than the former and France is no exception. At the same time, by examining the changes in urban density (number of inhabitants per km2), we see an increase in this density indicating a more intensive consumption of urban space concurrently with urban sprawl. Angel (2011) projects, according to one scenario, a growth of 75 to 190 % of urbanized spaces 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, particularly in France.

5.1.2. 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 the 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, planned zoning is established, the transition zones between urbanised and rural areas will always have particular forms that reflect the front of land take by connecting centres and/or by distribution along routes.

5.1.3. Peri-urbanisation of housing in France

Peri-urbanization is a major trend that began in the 1970s, and even several years earlier in Île-de-France. After slowing down in the 1990s, the figures post-2000 show 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 communes in which a large proportion of the working population commutes daily between their communes of residence (not included in the larger urban centre) and the latter. The development of these fragmented urban areas, separated from the city, is reflected in an urban sprawl, alternating real estate constructions, and extensive agricultural, wooded or natural enclaves. It is in these areas that the problem of the extension of artificial surfaces to the detriment of agricultural surfaces dominates. The role of agricultural landowners and their income choice, as described in the previous chapter, are the essential 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' manner (localized grouping of fragmented lots) or in strips built separate from each other. This movement has historically taken place in two stages: first, by increasing the number of so-called peri-urban communes, before continuing with a phenomenon of densification in these communes, in contrast with the decline of central cities (Figure 5-2). The 1990s were marked by a demographic recovery in these cities and their suburbs.

Today, peri-urbanization takes on more complex and varied forms. In particular, it is more often proceeding through the integration 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.

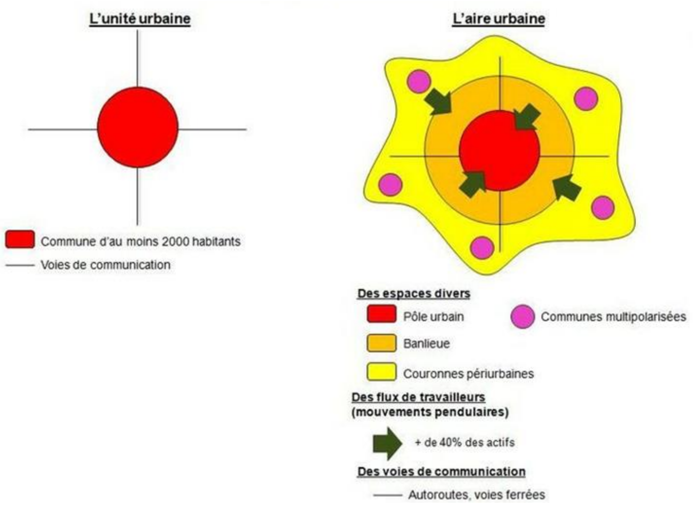


Figure 5-2. Between the centre, the suburbs, the peri-urban areas and its secondary centres © Aguilera, Bonin 2017

- **A vision of peri-urban areas in a state of constant change**

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 moderate judgments. These aim, firstly, at overcoming the initial enthusiasm for the new rural dynamic of peri-urbanisation (by counter-urbanisation or suburbanisation depending on the terms used in debates at the end of the last century) but secondly to avoid the image of rural areas as places with 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 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, and an attachment to these territories is stated: relocation from these areas is rare, and most households plan to remain in a peri-urban commune and not to return to the dense city. These are exactly the same reasons that drove the success of the first peri-urbanization movements in the mid-1960s. Peri-urban lifestyles have also evolved and are no longer strongly dependent on urban centres.

Box 5-3 - Growth machine hypothesis and Homevoter hypothesis: obstacles to peri-urban densification

According to the **growth machine hypothesis**, developers and owners of unbuilt land exert political pressure for less restrictive urban development policies.

According to the **homevoter hypothesis**, owners have an interest in politically supporting through the ballot box, municipal teams 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 affect the value of their assets. Indeed, various studies of this hypothesis show that municipalities with a large number of homeowners tend to implement restrictive policies, not only in the United States but also in France.

There are therefore **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, supported by newly arrived peri-urban dwellers who want to maintain their living environment and a low density of housing.

- **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 5-3) contribute 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 tending to develop in France.

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 from residential expansion tend to increasingly mix. If 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.

5.1.4. Social inequalities, urban configuration and land consumption

When households have the same preferences and differ only in income, the urban economics shows 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 or around the centre 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 5-6), which leads to **two dominant types of urban configuration**.

When space is homogeneous and households differ only in 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, because of 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 American West) 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 off-centre 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 the economy, explain the prevailing pattern. However, each of these two trends will lead to a different type of urban land consumption on the periphery.

Box 5-4 - The city is organized into socio-culturally homogeneous neighbourhoods

Location choices are associated with the benefits of social interactions. Social density makes it possible to satisfy the social identity needs of households and challenges the types of social organization in a city including households with different socio-economic characteristics according to income levels, social classes, nationalities, cultures, races, etc. The literature on 'neighbourhood effects' assumes that positive externalities are attached to well-off and educated neighbourhoods and, on the contrary, negative externalities for disadvantaged neighbourhoods. Segregation dominates the urban form.

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 are win-win policies.

Quantitative research on this subject reveals the preferential location of wealthy households either in outlying suburbs or nearby suburbs, thus contributing to the social inequality of the area (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-urbanization 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 5-5 - Social housing construction

The massive 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 developed 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 by make it eligible 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 low-income housing stock.

5.1.5. Impacts on urban households of the peri-urbanization of employment

When jobs shift to peri-urban areas or outlying suburbs (currently the case in France[16]), this movement may reinforce the trend of household relocation to outlying areas, as the main factor in locating residents in an area remains access to jobs.

However, if employees are forced to remain centrally located or in nearby suburbs, this can result in a 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. In the opposite case, when these households are far from the centre, job shifting is also detrimental.

A constrained urbanization and sprawl policy is therefore also conducive to better matching, although such restrictive land policies reduce market flexibility. However, this mechanism is probably not 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.

5.2. The debate on the role of amenities in land take

As shown above, amenities play a role in the choice of household residential location, usually 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, which is between urban and peri-urban areas (5.2.1), at the regional scale, which is between urban areas (5.2.2) or at the scale of France, between areas of high environmental value and other areas (5.2.3).

Box 5-6 - Site attributes: the three main types of amenities

Natural amenities correspond to the topographical features of the space - for example a river, or a seashore. **Historic amenities** characterise the aesthetic and heritage aspect of the city - for example monuments, architecture or green spaces. Finally**, modern amenities** are characterized by the presence or absence of public facilities, theatres, or the state of renovation of historic amenities. These last two categories of amenities are positive externalities.

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

5.2.1. 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. The spatial differences in land pressure due to amenities therefore depend on the influence of amenities on these two factors. Environmental amenities, classically characterized by their distance from the city centre, can influence the urban pattern. When these amenities, which are more pronounced at the periphery than in the centre, are taken into consideration, the land price function of household demand does not necessarily decline with further distance to the city centre. Households are ready to bid for locations far from the city centre despite higher transport costs, which is reflected in their willingness to pay for these amenities. This may explain the emergence of a fragmented form of residential development. However, in the most frequent case, demand for land by households and businesses remain higher in city centres.

• Urban green spaces are often 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, agree on the **high value of urban green spaces** and their potential role in a renewed appeal of central cities. The introduction of this component of urban green spaces, which can help mitigate the environmental impacts of urbanization, could also favour the reconcentration of housing or a 'recompaction' of the city, thus limiting the extension of land take.

Box 5-7 - Controversies around the compact city

Compact cities are encouraged because they reduce some of the environmental impacts of urbanization (see Chapters 2 and 3) and preserve the soil. It also aims to reduce GHG emissions by reducing travel. Densification by increasing the height of buildings meets these objectives, sometimes to the detriment of the well-being of the population and at the cost of construction costs often considered prohibitive by developers, while densification by filling available space (smart growth) alters land use. Conversely, on a more local scale and without specific design features, these two approaches alter the quality of the urban environment 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 property, natural areas and parks and gardens can generate negative externalities (sources of noise, nuisance and crime). This is particularly true in the less prosperous neighbourhoods. In a literature review, Laille et al (2013) show that indeed, nearly one hedonic study in six recorded negative amenity values for natural spaces in cities. It therefore depends on whether the space is integrated into an urban policy (developed, maintained, monitored) or left abandoned. One may also consider how urban spaces included within a 'green network' are 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 alternative value of the surrounding spaces. 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 remaining 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 of residential and agricultural activities is a source of conflict between urban dwellers and farmers in peri-urban areas. These conflicts are numerous and more or less diverse depending on the forces and nuisances generated by each of the parties involved. In this case, some large farmers have economic and lobbying power that leads them to attempt to influence policies to 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 shoreline, a river or a lake), household use of space 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 prevails, then the shape of the city extends towards the amenity areas, possibly in a discontinuous manner, thus generating urban sprawl.

The shape, location and type of amenities and externalities (urban, natural, social) are therefore crucial elements for understanding land take and segregation. For example, the protection of natural areas can increase land pressure near these areas. Moreover, by concentrating wealthier households, these amenities increase the municipalities' tax base and promote the provision of goods and services.

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

In addition to the traditional determinants of housing prices (intrinsic characteristics of housing) and those of wages (characteristics of employees), 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 significant drivers. Conversely, cold, rainy or particularly warm climatic conditions lead to lower housing prices and higher wages, compensating differentials for living in less popular places. While natural and climatic amenities play an important role in inter-metropolitan choices, it is social, cultural and recreational amenities that define quality of life.

Natural and climatic amenities have a greater impact on population growth than on employment growth. The same applies to amenities reflecting water-related recreation. Moreover, the growth in the proportion of forest cover increases 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. Finally, the amenities associated with winter sports also have a strong impact on local population growth. These amenities can therefore play a significant role in mobility between cities or towards areas of high recreational and/or environmental value. Beyond working people who have or are looking for work, these natural and climatic amenities partly explain the migration of **retired people**, whose residential location is no longer determined by a link to employment but more fundamentally by the accessibility to the services they need.

Similarly, these amenities play an essential role in the development of tourist areas, whether this economic activity is diffuse or highly concentrated. 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 they cause. These, which 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).[17] The artificial footprint of this type of housing has therefore increase substantially and should be taken more fully into account in land take analyses.

Thus there are tangible and potentially important links between local (demographic and economic) growth and amenities that can feed local development policies based on amenities.

Nevertheless, the climate change in progress, by modifying the spatial balance, may have consequences on the distribution of land pressure. In the United States, Rust Belt cities like Cleveland, Detroit or Pittsburgh could become attractive again compared to Sun Belt cities like Phoenix or Dallas if they become exposed to too much heat and periods of drought.

5.2.3. French amenities have an international appeal

France is characterized by a strong attraction to foreign people for 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, collective wealth and the new interurban mobility of the labour force. The extent of these international lifestyle migrations depends in part on the geography of the country. In this respect, France stands out from most European countries where geographical variables are powerful predictors of urban growth.

The effect of this foreign demand on the development of certain areas, and consequently on the land pressure that characterises them, is indisputably strong. France is attractive due its natural amenities, quality infrastructure and the presence of an 'international city'. The *Wealth Report* remains a useful reference in this respect, particularly for its *Prime International Residential Index* (PIRI), which lists the 100 best destinations for high-end residential investment. For the year 2016, French examples include Val d'Isère, Cap-Ferrat, Provence, Gascony and, of course, Paris. Added to this are the pressures exerted on areas by tourist demand in the form of hotel and recreational tourism areas. Foreign real estate investments, as well as tourists and new residents from elsewhere, certainly contribute to the French economy and can revitalize certain regions through their local spending, but they also accentuate pressures on the French real estate market and the demand for built land.

[17] Arnold C. (2016). Le parc de logements en France au 1er janvier 2016. Insee Focus, No 73.

5.3. Land and property policies that may limit urban and peri-urban expansion

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

Land and property markets respond to household demand for land and housing. They are characterized by the following rules:

- Prices per residential unit of service decrease as distance to the centre increases;
- The optimal lot size increases when one moves away from the centre ;
- Land use densities decrease with distance to the city centre.

What tools are available to influence household density and spatial distribution? While zoning and taxation are the classic answers (cf. Chapter 8), 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 the characteristics of land and real estate markets. It allows the project developer to increase the density on one plot by purchasing unused rights on another plot in the same area.

This is the land use coefficient (COS) market as it theoretically exists without having been put into real practice. 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 claim, must be higher than under a classical uniform regulation scheme. Also, the area subject to this type of regulation must correspond to the expectations of the local community, the density limitation threshold must be strictly applied and the district must not present areas that are not subject to regulation, thus offering builders alternative opportunities for new construction.

The establishment of a market for tradable building rights is confronted with the fear of concentrating detrimental activities (extreme density in a single place) or the question of the effective reduction of the total quantity of buildings, in comparison with a more traditional uniform system of regulation. Yet, in the ideal hypothesis of an optimal distribution of land and urbanization gains, the transfers of building rights are likely, according to economists, to satisfy the public interest and the private interest.

In France, the use of this tool is negligible: the lack of a market able to set consistent prices, legislative constraints and the prior authorisation system in place partly explain this fact. It could possibly develop under the impetus of the ALUR law (2014) which created a transfer mechanism of constructability in the zones to be protected on the basis of their landscapes.

• Land purchases and development projects as a policy tool against land take

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 4 and 8) 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 results are not there, and the outcome of this policy is disputed in the literature.

The anticipated effects of greenbelts concern the restriction of buildings and their prices, the improvement of environmental amenities on the site and its surroundings and the scarcity of supply in relation to demand. Furthermore, a green belt would significantly reduce the effects of urban heat islands, as shown by CNRM models simulating a green belt around Paris. In France, some work shows that these belts would have a protective effect on the area targeted and nearby, while attractiveness is enhanced on a larger scale. At the same time, the scarcity effect causes prices to rise and changes the demand for housing by directing it to other places.

Upgrading areas through **urban renewal**, on the other hand, helps to maintain and attract the population to urban centres. This can take the form of projects, the defining of renewal zones, or renovation-renewal programmes for housing in disadvantaged neighbourhoods. The implementation of major public projects (transport, green spaces within cities, projects promoting social connections, etc.) helps to reorganise neighbourhoods by encouraging builders to concentrate their actions near these new amenities rather than on the outskirts. Potentially large-scale, it has been found that communities need good administrative management capacity to manage these projects.

The problem of **vacant land** and its **redevelopment** is logically at the heart of many urban strategies[18]. 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 use (dilapidated housing, industrial or military installations, etc.). Residential mobility also contributes to vacancy, as does a city's geographical capacity 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 neighbourhoods in question. In the event of signs of decline in certain neighbourhoods or, more generally, in the event of abandonment of the city, a proactive public policy makes it possible to anticipate this phenomenon in order to better counterbalance it, all the more so as the rehabilitation of degraded neighbourhoods increases the value of real estate in neighbouring neighbourhoods.

Forecasting 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 incentive policies that enable owners to cooperate, by granting higher densification potential in targeted spaces. If necessary, these policies would be complementary to the actions carried out by public land establishments 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 affects costs. These obstacles are amplified on industrial wastelands 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 recovery should be implemented. In the case of shrinking cities, these spaces are opportunities to modernise the city, including 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 to limit the increase in vacant land in urban areas.

Dynamics by 'substitution effects' are emerging. In Scotland, for example, green belts are accompanied by policies to densify urban areas, targeting the conversion of polluted sites. In France, contractual tools of the ZAC type can be used to force the reconversion of strategic areas in the PLUs, which the private market ignores.

- **Transport policy: a key element for compact urban development**

The construction of transport infrastructure generates urban sprawl, since it allows people to live further away. At the same time, it fluidizes transportation and, when it comes to public transit, it makes urban centres accessible to a greater number of residents, and reduces pollution and overall energy consumption.

Transport policy often aims to create peri-urban secondary centres as multimodal transport platforms or mobility nodes, one of the objectives of which is to reduce the dispersion of housing in the peri-urban suburbs, but the results are not clear: although they make peri-urban sub-centres more attractive (especially residential), the reduction in the dispersion of buildings is not as great as decision-makers would like. Some experts advocate the implementation of Transit Oriented Development (TOD), consisting of the coordination 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 spatially concentrate the location of firms in a given area, the deployment of transport infrastructure can lead to dispersion in the location of these activities, due in particular to the improved dissemination of knowledge externalities (see Chapter 6)..

5.4. The economic and social importance of housing and construction

Beyond the need for housing[19], which is necessary to keep in mind when trying to limit the extension of land take by urban and peri-urban housing, it is important to consider the economic importance of a sector such as construction.

The construction sector is the leading employment sector in France (with 1.3 million jobs). However, between 2008 and 2015, this sector lost 152,000 jobs, its output fell by €22 billion (-18%) and its investments fell by €2.5 billion (-26%), largely due to

[18] It is very difficult to get an idea of the artificial surfaces concerned by this vacancy. Of course, it concerns housing and we know that the number of vacant homes in France has increased sharply, from 1.8 to 2.8 million homes between 1986 and 2016 (C. Arnold, 2016, INSEE Focus, 73). The record of brownfields and vacant office properties remains to be done

[19] According to the MTES figures, in one year, from October 2016 to September 2017, 496,900 housing units (cumulative twelve-month cumulative data) were authorized for construction and 414,000 housing units were started, a respective increase 12.1% and 17.6% compared to the previous twelve months. These figures will therefore be compared with the methodological guide on the territorialization of housing needs published in February 2017 by the Ministry of Housing and Sustainable Housing.

the sharp decline in housing investment since 2008. Following the 2008 crisis, the number of new homes built in France fell considerably. It rose in 2015 but does not yet cover the annual demand that comes from the increase in population and the number of households (+25% since the 1990s).

Housing demand also comes from inadequate housing, which, according to INSEE, affects 900,000 people. This situation is not uniform across the territory. These are areas that are under greater stress and have not been able to offer housing, indirectly causing an increase in the cost of housing in these areas. Inadequate levels of housing also generate significant direct costs, in the order of 1.3 billion euros to alleviate situations of marginalisation (emergency accommodation). Housing subsidies amount to more than 40 billion in 2016. The indirect costs of social care are also significant, estimated at several billion euros.

As part of this review, the impact on employment and value added of an increase in investment in the construction sector was simulated using the multisectoral macroeconomic model ThreeMe[20]. The results of this show that, on the one hand, the construction sector contributes to job creation and growth and, on the other hand, construction in peri-urban areas, in stressed areas, is able to meet the housing needs of households and to contribute to the fall in property prices.

Real estate also forms a significant part of French people's wealth. The land and buildings they support represent 86% of France's non-financial assets, which make up the bulk of the country's assets, and which have increased in value by a factor of 3.5 since 1990. The value of land alone supporting construction increased sixfold between the end of 1997 and the end of 2015: it represented half a year's net domestic product at the end of 1997 and stood at 3.1 years of GDP at the end of 2007. Overall, assets linked to urbanisation have contributed to most of France's wealth since the early 1990s. This contribution is mainly due to the increase in market prices at which the stock of existing buildings and built land is valued, but constructions on new land during the period also played an important role. Beyond its remarkable increase, this real estate capital amounts, in short, to a transfer of wealth to urban owners, which leads Piketty (2013) to state that real estate capital is today one of the main sources of social inequality in the West, and more particularly in France.

Piketty's data also shows that the value of built-up land (the contribution to national capital) is not only derived from demand factors, which we have focused on in this chapter, but also from supply factors, precisely because land supply is fixed. However, in the face of sustained increases in demand, any restriction on supply will necessarily result in higher prices. Studies on the impact of urban planning regulations and other land control policies are numerous. Such measures may prove to be effective instruments to curb the expansion of cities, but it must be kept in mind that they inevitably result in higher land values in cities and, at the same time, higher housing costs. Any rarity, regulatory or natural, creates a 'rent' from which property owners benefit in this case.

5.5. Conclusions and policy tools

Household location strategies reveal a trade-off between numerous parameters that result in urban sprawl and/or peri-urbanization 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 territories 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 communes. From this finding, public planning policies are emerging as tools for improving social distribution and taking greater account of the multifunctionality of cities. The urban models are the basis of much discussion through the questioning of social as well as environmental limits of compact city models, suggesting a controversy on the objectives of densification. On the other hand, the rehabilitation of vacant spaces and industrial wastelands within already urbanized spaces 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 means of local development, the complexity of which is however well-documented. In intra-urban areas, we have seen that the development of 'natural' amenities can be a drawing factor for residents, knowing that these same amenities can also limit the environmental impacts of land take. Natural amenities are also the focus of the development of tourist activities which, in addition to their economic role, have an impact on land take through the extensive development of second homes and other tourist hotel facilities.

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

[20] The ThreeME model was jointly developed by OFCE and ADEME. See in particular "The dynamic and long-term properties of the ThreeME model", OFCE Review No. 149, 2016.

6. Determinants of land take by enterprises and transport infrastructure

Along with housing, the location of companies and the construction of transport infrastructures are the other two drivers of land take in France. According to Teruti-Lucas, businesses and infrastructure account for the majority of artificialized land (Figure 6-1). Thus, industrial, commercial and public service activities represent, in 2014, 20% of artificial surfaces (to which could be added the 9.5% of artificial land linked to agricultural activity), while transport infrastructure (road and rail) represented 28%.

According to Teruti-Lucas, the growth rate of artificial surfaces between 2006 and 2014 is less pronounced for these activities than for housing (Figure 5-1). Nevertheless, in a comparative analysis of 15 European urban areas, M. Kasanko et al (2006) [21] shows that, for three French cities considered (Lyon, Marseille and Grenoble), non-residential surfaces increased more rapidly than residential surfaces (Figure 6-2). In other cities, including Dublin, Palermo and Heraklion in Greece and Pordenone in Italy, residential space growth has been faster. Moreover, the increase in land take for transport and infrastructure is almost systematically accompanied by a complete waterproofing of soils, contrary to what is happening in housing (Figure 5-1).

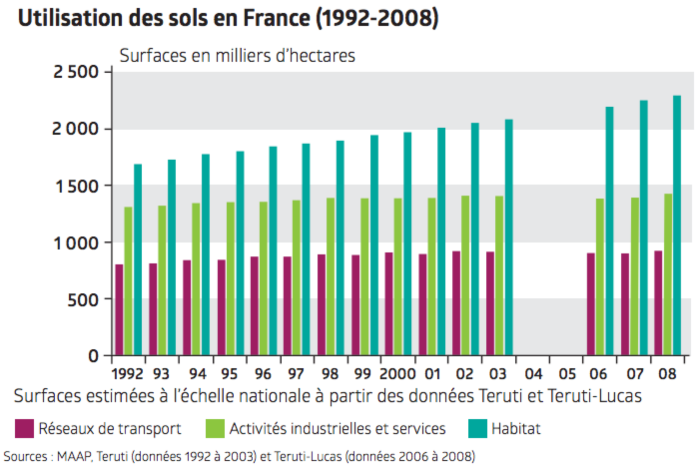


Figure 6-1. Economic land, one third of artificial surfaces (source: Teruti-Lucas)

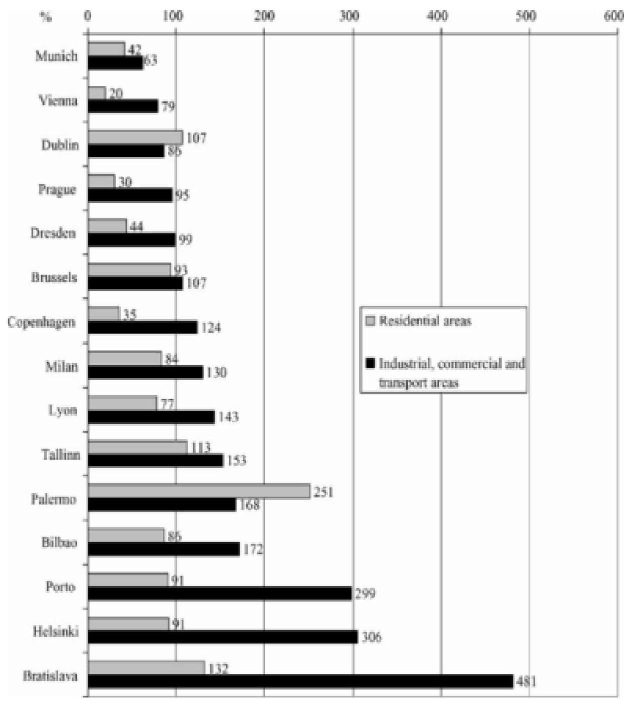


Figure 6-2. Growth rates of residential, industrial-commercial and transportation areas from the mid-1950s to the late 1990s (M. Kasanko *et al.*, 2006).

6.1. Business and industry location strategies

However, as will be shown later, 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. Potential research could focus on surface-intensive activities such as commercial or logistics activities. As the latter appear better documented, the following will focus on the development of logistics platforms.

[21] M. Kasanko et al. (2006) '*Are European cities becoming dispersed?*'

6.1.1. Economies of scale and agglomerated economies: sources of urbanization and metropolization

The quest for economies of scale in production, accentuated by technical progress, is the basis of the concentration of economic activity and therefore of urbanisation and metropolisation. 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 for economies of scale, various forms of so-called agglomeration economies have been identified. Market relationships, with respect to goods markets and labour markets, play a significant role in the location choices of firms. Because of 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. Simultaneously, while they 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. Lower transport costs, particularly with the revolutions of railways and steamships, might have called these mechanisms into question. However, this decline in transport costs has had little impact on labour markets and has expanded market areas.

In addition to increasing internal corporate returns and agglomeration economies that pass through the markets, external returns to firms are also a source of agglomeration. These externalities combine several dimensions, those resulting from services to numerous and highly specialized enterprises, from a specialized labour force allowing a good matching of supply and demand on the labour market and, finally, from the emergence and diffusion of new ideas, allowed by proximity, source of innovations when it comes to exchanging information 'face-to-face'. These agglomeration savings can be divided into two classes: those achieved through co-location with other firms or institutions in similar or related fields, commonly referred to as 'location savings'; those achieved through location in a large city, referred to as 'urbanization savings'. The economies of location specific to the sector of activity to which the industry belongs, push, for example, the aerospace industry to group together in particular cities. In France, the largest concentration of the aerospace industry is not in Paris, but in Toulouse. The pharmaceutical industry in Lyon is another example of an industry whose concentration is mainly driven by localization economies, including the presence of a specialized and experienced labour pool, and training and research institutions. This distinction into two categories of agglomeration economies has been revisited more recently and the microeconomic bases were more specifically highlighted to show the role that firms that establish relations between themselves on the markets play in the agglomeration. Three types of mechanisms are now distinguished, covering all markets (labour, intermediate goods and final goods). They are considered as key to assessing the benefits accruing to enterprises when they are located in agglomerated areas: *sharing*, which refers to the sharing of indivisible goods and the benefits of diversity, the adequacy of supply and demand, which increases with the increase in the number of people (*matching*) and *learning* and innovation, which concern the creation and dissemination of knowledge. The way in which each sector of activity engages one or more of these dimensions makes it possible to understand its greater or lesser dependence on the centre and its greater or lesser propensity to move away from it.

Beyond the ongoing debate and research to identify the relative weights to be attributed to these various factors, their change over time and their sustainability, these different mechanisms have resulted in the well-known metropolization movement, which is based on the tide of globalization and on the power of agglomeration economies and the contraction of 'space-time'. It is a global phenomenon, drawing a relative concentration of innovative social and productive sectors to the largest cities. These major cities are the main engines of economic, scientific and social development. In France, these mechanisms are responsible for a geographical rebalancing, marked by the growth of its principal regional metropolises, articulated and coordinated with Paris, which maintains its status as a global city. Thus, in 2012, Ile-de-France, which covers barely 2% of France's metropolitan territory, accounted for 19% of the French population and produced 30% of the Nation's GDP. This geographical concentration of industry, accompanied by tax policy, has facilitated 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 which have contributed in France, and more generally in Western Europe, to significant increases in 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 societies and 'post-industrial 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. Thus, the arrival of Information and Communication Technologies (ICT) has had no visible impact on the decentralization of economic activities and urban populations. The activities most in demand for information (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 remain profitable, the producer must be able to deliver the product to customers at a reasonable cost. It is easy to understand that the construction of motorways, the arrival of refrigerated transport and other logistical innovations were prerequisites for the development of Rungis. The same reasoning applies to services, with the only difference being that we are now dealing with the transport of information. At *the national level*, the effect of NICTs, like previous transport innovations, favours the strengthening of agglomeration forces.

On a finer scale, transport and the new communication technologies, far from contributing to the dispersion of activities by reducing transport costs, contribute to the reinforcement of polarisation effects. Indeed, both transport and ICT are based on a logic of mass movement in order to implement economies of scale specific to transport (large aircraft or giant ships). This consolidation leads to a concentration of flows through hubs which are similar to vast suction and discharge pumps. The world's largest airports and seaports are also located in the world's largest metropolises, acting 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 maritime containers handled worldwide!

Similarly, the backbone of the Internet lies in the depths of the oceans thanks to nearly 300 submarine cables, which in the case of the highest capacity can handle tens of millions of simultaneous connections. Their geography on a global scale is organized in major East-West axes between global economic hubs, North-South links are secondary, and South-South links still almost non-existent. It is therefore primarily the world's major coastal cities that are interconnected, further accentuating the effects of polarization.

6.1.2. 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 intensive professional activities, often also the best paid, in the largest metropolises has the effect of increasing wages and land prices. Therefore, 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. This last dynamic applies especially 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 logic of land ownership and not wages (or other local conditions) that will encourage companies to decentralize. Indeed, the primary attribute of an urban area is to constitute an integrated labour market. It is the residence-work interactions that define the urban area's perimeter, more or less extensive 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 on 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, for locations 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 spread. 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 secondary towns and cities form 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 less and less of an obstacle to daily interaction, the multi-location of activities and people is developing, the borders of cities are not disappearing but changing in nature - they cross territories internally more than they delimit them.

Companies play a major role in this reconfiguration. While consuming land (Figure 6-1), they structure by their location a large number of other location choices: the emergence of edge cities in the United States, for example, is leading to the spread not around the city centre but from the 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 (Figure 6-3), irrespective of the urban centre under consideration (Figure 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 that there is a strong correlation between the gradient of employment density and that of population density.

This development is explained by stronger growth around peripheral areas. Thus, in the United States, the majority of employment growth between 1985 and 1995 benefited rural areas. 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.

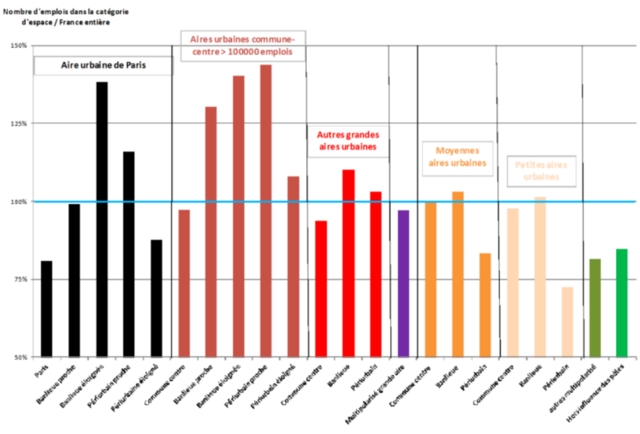


Figure 6-3. Relative change in employment from 1982 to 2008 according to the centre-periphery gradient (Sénat, 2012, INSEE)

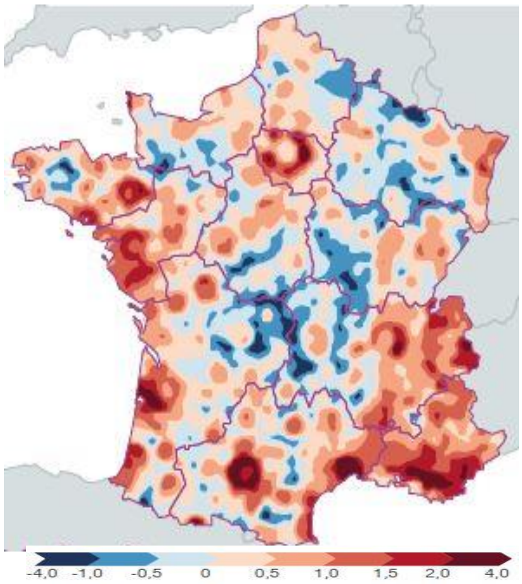


Figure 6-4. Annual rate of change in employment between 1975 and 2012. Source: CGET, 2016

- **Polycentric cities or regional systems: two types of reconfiguration for employment 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 alignment of the decisions of the initial economic actors towards the periphery, since this is what will guarantee the access to local markets for the companies that relocate. 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 the suburbs or suburbs 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 continuous increase in land consumption for economic purposes.

The growth of metropolitan centres eventually reaches the surrounding towns and medium-sized cities and encloses them in an integrated regional system. These dynamics are rarely reflected in public policies: the intermunicipal approach remains confined to the municipalities adjacent to the urban centre, and the 'metropolitan centres' mostly support relations between large metropolises. Apart from 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 spirit of the Territorial Conferences of Public Action, created by the MAPTAM law, but this approach is not yet fully operational. Peri-urban areas remain territories in the making, 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 dynamic zones.

Box 6-1 - The example of Oise

The main difficulty for public authorities seeking to act on increasing land consumption in the periphery is that it occurs most often in areas influenced by more than one administrative zone: Oise has for many years been directly and adversely affected by the presence at its doorstep of the Paris region, without benefiting from the 'protective' effects for its land of a very protective development scheme such as that of the Paris region. Located in the Hauts de France region (and before that in Picardie), Oise has never been covered by the Master Plan for the Ile-de-France Region, whereas some communes are less than 50 km from Paris. This situation (also found around Geneva) calls for more cross-border cooperation between local authorities.

- **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. Agglomeration economies play a fundamental role in the location of service and high-tech companies, where they are particularly important. For cities of the same size and offering the same urban economies, amenities can have a role in growth to the extent that they attract skilled labour. They will be able to offer lower wages but will be required to pay higher rents. Residential amenities therefore play a role in the attractiveness of regions for businesses and have an impact on land take.

Business incentive policies based on amenities can hope to attract mobile entrepreneurs and inventors. However, the decisive role of agglomeration economies and specific production variables makes the implementation of such policies complex. Studies show that amenities play on the appeal to skilled labour, especially in medium-sized cities, but not decisively in large cities where agglomeration economies are largely dominant and neither in rural areas where, on the contrary, they are too weak to be compensated by amenities. Amenities, on the other hand, can play an accompanying role. By attracting labour, including skilled labour, they can facilitate the establishment of businesses. In dense areas where agglomeration economies are important, fighting against negative externalities linked to density (congestion, crime, air pollution, disappearance of natural spaces) can be a complement to economic incentive policies.

- **The land consequences of company location logic: a literature gap**

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. Here, as for households, land could/should play a role as a force for dispersal of economic activities and explicitly be included in the factors taken into account when deciding the location of firms. To understand this absence, one must consider that, contrary to the case with households, the cost of land can be considered negligible in the choice of the location of firms, given the weight represented by the gains from agglomerate because of the strength of agglomeration economies. Thus, except in the case of high land-consuming activities such as logistics platforms, the spatial, regional and urban economy, as well as economic geography, cannot answer the question of 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 location distance in the metropolitan area, with the direct consequences of restructuring (or multilocation) on land consumption. From this perspective, the massive outsourcing of activities and the ever finer segmentation of sectors and branches are resulting 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 a differentiated growth in the different business activities of the city, the different districts of the city are likely to have different growth dynamics: while the centre will have a relatively stable demand for land, only sensitive to the overall economy of the city, 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 the same barely artificialized zone may suffer an economic backlash that will see it turn into unused wasteland.

6.1.3. The dynamics of setting up logistics platforms; the example of a sector that uses large areas of land

Freight transport and logistics have developed rapidly in metropolitan areas, with multiple indicators, one of the most significant of which is the number of warehouses and, more generally, buildings dedicated to logistics functions. Behind the problem 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 located in isolation or within multi-purpose business parks, but **clusters of warehouses** are now part of the logistics real estate landscape. A **logistics hub** 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 of Storage Facilities and Logistics Areas in France in 2015* from the Ministry of the Environment identifies 'logistics areas', including 'dense logistics areas' and differentiates them from 'isolated warehouses' as follows:

- A **logistics area** is a territory composed of at least three warehouses or logistics platforms (EPL) of more than 5 000 m2 and on which each EPL is located less than six kilometres from another EPL of the same logistics area. These areas are home to 81% of the EPLs of more than 5,000 m² and are located around major French agglomerations. The three extended logistics areas located around Paris, Lille and Lyon account for 23% of the EPLs of more than 5,000 m².

- 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 industrialists and are on average smaller (15 800 m2). Thirty-six per cent of them are located in rural areas and 20 and 20% in urban units with fewer than 2,000 inhabitants.

The location of logistical storage facilities has evolved considerably and responds to determinants linked to urban configurations. The logistical spread of this phenomenon requires planning strategies to take it into consideration on an ad hoc basis.

• Determinants of warehouse location

Three factors explain the increase in the number of warehouses in large cities: (i) outsourcing of logistics; (ii) globalization of trade; (iii) development of new patterns of urban consumption. For example, e-commerce markets offer new services such as same-day delivery, requiring warehouses located close to major cities. These dynamic logistic functions of the large cities are expressed in buildings and warehouses where goods shipments 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 150,000m², have developed since the 2000s. The way in which these logistics facilities are located and arranged contributes 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 the point of becoming 'almost insignificant'. The proliferation and expansion of warehouses and their **preference for easily accessible suburban areas** is due to the intensification of long-distance links between economies in remote countries.

• Evolution of the location of logistics warehouses: 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 the second belt around major agglomerations, particularly in 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 communes in the Ile-de-France region host logistics areas: 24 of them contain 42% of the utilised surface area, which indicates a high concentration in a limited number of communes. Conversely, 621 communes host 58% of the surface area, an indication of sprawl.

The majority of large retail distribution centres in Ile-de-France were isolated facilities or 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 powerful concentrations of logistics activities are emerging, to which the Ile-de-France municipalities must react.

Since the late 1990s, in industrialized countries, growth in both the number of establishments, and even more so in their square metres, has exceeded 50%, and in some cases reached 200% (Box 6-2). This increase is particularly evident in large cities, demonstrating a **metropolitan polarization of logistics functions**. In the Paris basin (Figure 6-5), the average distance of warehouses to the geographic centre of Paris has fallen from 155 km in 2000 to 110 km in 2012, **narrowing around the Paris agglomeration**. Within the Paris metropolitan area, however, these facilities have also experienced sprawl.

Box 6-2 - Amazon's warehouses in Los Angeles

Amazon has contributed to the growth of warehouses in the United States, particularly at the fringes of large cities. In Los Angeles, three major distribution centres have been built since 2012 to serve Los Angeles, which was previously supplied from Arizona. They are located about 110 km from the city centre (City Hall). These warehouses in San Bernardino, Moreno Valley and Redlands have sizes of 90 000, 110 000 and 65 000 m².

Instant delivery services (delivery in two hours) are also under development and 5 urban warehouses exist today in the dense fabric of Los Angeles. Atlanta and Los Angeles each recorded a **tripling in the number of establishments** classified as warehouses in the 2000s.

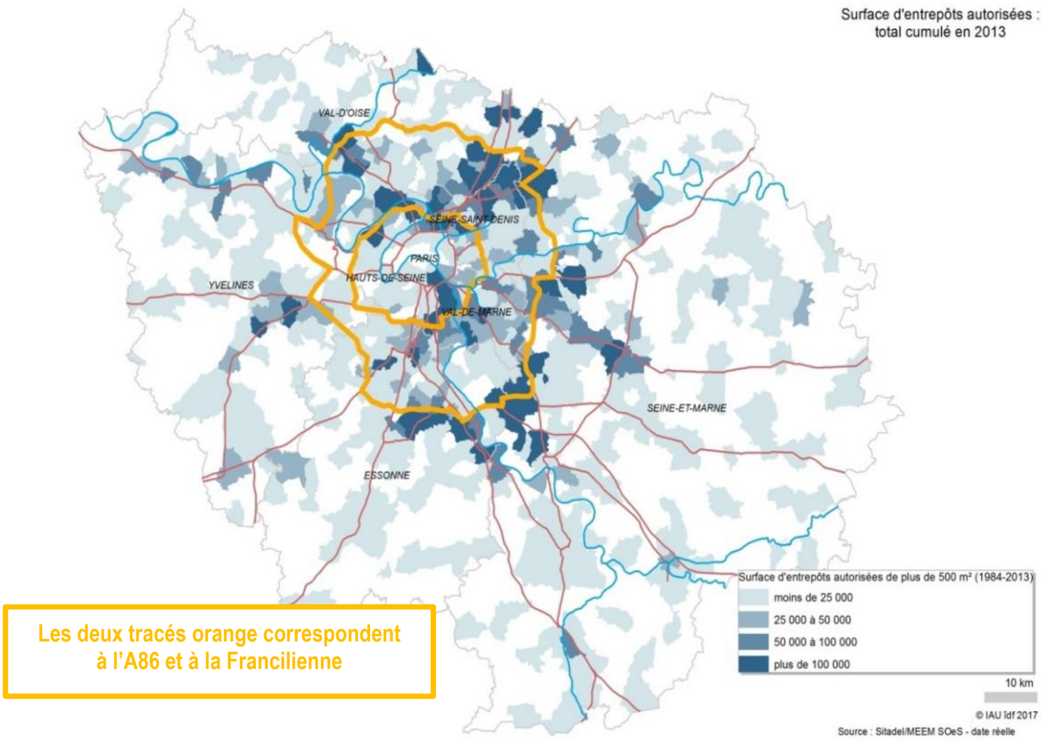


Figure 6-5. Warehouse construction in Ile-de-France, 1984-2013. Source: with the kind permission of Corinne Ropital, IAU

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 concentrates 20 million square metres of useful 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 'an important local market for logistics services, proximity to nodes of infrastructure networks, an abundant labour market and an **active professional real estate market**' (Savy, 2006).

- **Logistic sprawl**

While warehouses were traditionally located at the fringes of the dense urban area, or even at 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 inland 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 today 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 distance could reduce the total net distance travelled by trucks, since the destinations to be delivered (businesses and households) are frequently also far from city centres. However, the dispersion of logistics platforms is greater than that of other activities. We can thus consider that, overall, there has been an increase in the distances to be travelled to deliver goods in the dense Ile-de-France zone, but the savings in land costs and the efficiency gains made possible by a peripheral location have largely offset the additional transport costs for those deciding on new locations. On the other hand, this optimization leads to an urban sprawl effect, with a direct effect on land take and landscape transformation.

Box 6-3 - Towards vertical spaces in the city centre

In Japan, municipalities embrace very large logistics buildings with several storeys. Prologis has built logistics buildings in the heart of Tokyo with more than seven floors in the immediate vicinity of residential buildings and shopping centres. In France, Sogaris specialises in urban logistics.

The return of logistics activities to dense urban areas makes it possible to reduce the last kilometres of delivery, thus massively reducing the transport flows (and thus the total vehicle-kilometres) and reducing the logistics land footprint. The city of Paris has thus implemented a policy of returning warehouses to the centre. On the one hand, it has actively supported the creation of urban logistics areas in the central districts and, on the other hand, has reserved areas in its PLU (2016) for future logistics functions, if possible with rail or river penetration within the dense area.

For its part, the Ile-de-France Region has carried out studies to identify the logistical applications that could potentially be deployed in dense areas and the land and legal tools at its disposal. The regional planning documents (the 2013 SDRIF and the 2014 Urban Travel Plan) partially contain objectives for the recentralisation of logistical functions. However, given the context of low transport prices and land pressure in the city, which is generally unfavourable to logistics activities, it is expected that logistics buildings will continue to develop on a peri-urban basis.

- **Logistics planning**

The final choice of location for logistics platforms results from a bilateral relationship (sometimes very unbalanced) between a logistics developer and a municipality. In attempting to regulate this process, France was one of the first European countries to ensure that merchandise were taken into account in urban planning documents, but it was not until the NOTRe law was passed in 2016 that the SRADDET (regional planning, sustainable development and territorial equality scheme) was created. Developed on a regional scale, this planning document is based on the model of the Ile-de-France SDRIF that has existed for several decades (1965). Its aim is to structure the regional territory by focusing activities around some twenty reception sites, 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, an insertion of this issue in the regulations could have a significant impact on the issuance of permits and thus influence the location of logistics terminals to create a more effective distribution of these facilities.

6.2. Transport infrastructure in France

According to the Observation and Statistics Service of the Ministry of Ecology (SOES 2016), the total footprint of rail and road networks in 2012 (last known date) was 20,970 km2, or 3.8% of the French mainland. This estimate is close to the European average, which exceeds 3% of land use in the Member States (EEA 2005). Mainland France (excluding Corsica) thus benefits from the largest road network in Europe, totalling 1.073 million linear kilometres (compared with 644 million for Germany, which occupies second place) (SOES 2016).

Roads make the largest contribution to land use by transport infrastructure with 1,230,000 ha, approximately equal to the size of the Ile-de-France region. Rail lines occupy second place with 867,000 ha of ground surface, most of which is permeable soil. No such estimates appear to have been made for waterways. However, by comparison, the literature dealing with the construction of transport infrastructures (road and rail) and their direct impact on land take is surprisingly sparse, rather tending to focus on the effects of such infrastructure on development in general and on models to measure their impact on land use.

Box 6-4 – Analysis of the 'Transport infrastructure' literature

Sixty scientific articles from the Web of Science were reviewed and archived for expert review. The analysis by keywords reveals the large focus on the term 'urban'.

Almost all of the articles deal with road infrastructure. Only two documents related to high-speed rail lines were identified in the corpus and no source was identified for waterways. This low representation of work on railways is surprising, given the constructions carried out in recent years.

6.2.1. Calling into question the effects of transport infrastructure

The indirect effects of transport infrastructure, often described as structuring, remain difficult to quantify because it is so difficult to isolate infrastructure from other factors involved in spatial and territorial changes. The numerous studies devoted to this question deconstruct the 'myth of the structuring effects' that the post-war boom had contributed to creating.

- **Putting the 'structuring effects' of transport infrastructure into perspective**

France has seen several waves of modernisation of its transport networks, two of which are significant: the first concerns the development of the rail network, first on the network of national interest between 1840 and 1860, then with local lines through the Freycinet plan from 1880 to 1914. France then undertook, from the 1960s onwards, to make up for its lack of motorway infrastructure in order to reduce regional disparities, thus confirming the link between transport and territorial development.

As the political, economic and cultural capital of France, Paris dominates the French transport space since the royal roads first radiated from Paris to the major provincial cities and borders. In the 19th century, Paris railway stations ensured the lasting prominence of the capital in its role as the nodal point of the railway network. This is reaffirmed with high-speed lines (LGV). Motorways were also developed radially from Paris. It was not until the 1980s that transversal axes were gradually built to reflect reality in the French network. Air transport brings the Parisian focus to a peak with the airports of Roissy and Orly.

It is true that the relationships between Paris and the major provincial cities are the only ones that can economically support high-speed transport links. This is particularly true for high-speed lines that require new infrastructure and high transport capacity. Their profitability can only be ensured by very large traffic flows which exist primarily between Paris and the major provincial metropolises, and only secondarily between the latter. In short, a TGV line is only profitable between Paris and a very large provincial city. Therefore, the relationship between transport and metropolisation results in the snowball effect. Metropolises generate the largest traffic flows, which justifies the location of the most efficient transport operations there, which in turn reinforces the focus on the latter.

Thus, the major determinant of the construction of transport infrastructure is first and foremost to meet traffic demand. But it in turn provides a location with more opportunities for accessibility gains. Traffic creates more traffic, especially between larger cities and within urban areas. Therefore, the link between transport infrastructure development and territorial development should be questioned. There is no direct relationship between development and transport infrastructure (road or rail). It is a prerequisite, but in itself insufficient. In the long term, they tend to accentuate the major trends at work by reinforcing dynamic areas through a suction effect and weakening other areas which become mere transit areas or, at best, recreational areas.

Box 6-5 - Stakeholder involvement and territorial governance

Cities and regions are increasingly involved in infrastructure financing, where 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 it has been demonstrated that a 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 constitute '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 local or regional dynamics at work in France. They therefore contribute by 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-urbanization. Since the 1970s, motorway intersections and major city entrances have gradually become favoured locations for commercial and business zones. The entrances to French cities are now similar to long, uniform trade corridors from one city to another, with the frequent consequence of very severe landscape degradation.

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

The development of large transport infrastructures places two divergent spatial rationales under tension, depending on the scale (Figure 6-6). The **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 level, and accessibility at local and regional level. The local and regional logic (**territorial logic**), is generally driven by local authorities in the name of the general interest, and responds both to national issues of equity and solidarity and local issues of attractiveness.

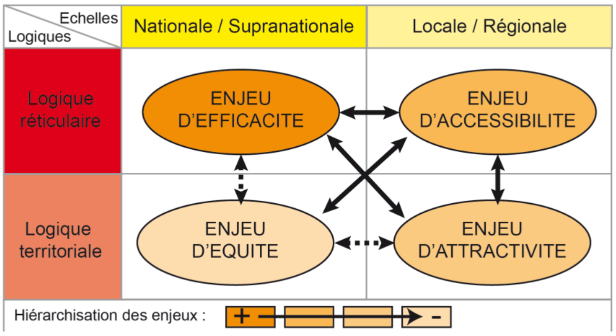


Figure 6-6. Spatial rationales; complementary or contradictory, according to geographical scales. (Facchinetti-Mannone & Richer 2011).

Travel-time optimisation, which in the name of economic profitability 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 on 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 definition of railway or motorway routes, the choice of location of 'coveted equipment' such as TGV stations or junctions, or the definition 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 attractiveness, 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 (cf. Chapter 1.).

6.2.2. 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 (Land Use and Transport Integrated) models have been developed since the 1960s to understand the interactions between transport and land use. Many models exist under different paradigms (Figure 6-7). 'Urbanism' has, for example, been used to test urban fabric densification policies to show the consequences for transport networks. Today, they rely on remote sensing as the primary source for identifying direct and indirect land use changes associated with infrastructure development. It requires both a high typological accuracy of land use (e.g. Airport, Commerce, Highway, Industrial Building, Residential Building, Public Park, Natural Park, Public Square, Railway Right-of-Way, Land Reserve, and Water Surface) and data on land use changes over time.

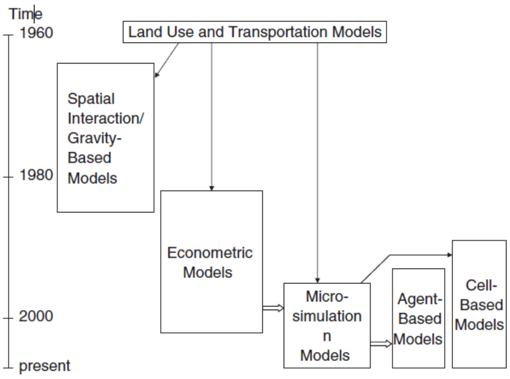


Figure 6-7. Chronology of LUTI model development (Iacono, Levinson et al. 2008)

The models measure the influence of the transport network on land use change. Numerous studies have shown the correlations between the development of motorway networks and its impacts on land use and population trends. The analysis of the evolution of the Twin Cities agglomeration (Minnesota, USA) over the period 1958-2005 shows, for example, that the probability of change of occupation increases with the proximity of highways for commercial and industrial activities. However, this proximity has no effect on agricultural plots. The probability of change is even negative for residential areas.

6.3. Conclusions and policy tools

Economic activities undertaken by businesses, as well as transport infrastructure, play an important role in urban patterns, and their location has a direct impact on land consumption. The land dynamics that the location of economic activities generates 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 rely principally on the rationale for the location of transport companies and infrastructure (with, for the latter, an environmental impact overlay), 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 is such that the city centre should be reconsidered 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 productivity drivers 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 metropolisation of logistical functions, 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. The integration of the logistics function 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 resulting more efficient management of infrastructure 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, a history of major infrastructure project decision-making would be very useful to better understand the choices made in the past, starting with the Departmental 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 take into consideration impacts and nuisances more generally.

Roads represent the focus of the majority of research while the high-speed rail network is increasing. The effects of high speed rail are often addressed from an economic point of view but without sufficiently measuring the impact of new infrastructure of this type on land use. It therefore would appear essential for all regional sciences to address this issue. Conversely, local rail lines are regularly closed, raising the issue of 'reverse land take' which may create opportunities for biodiversity, and for environmental modes of transport (greenways, cycle paths, etc.).

7. The unique characteristics of land take in coastal environments

Coastal areas are subject to the same types of land take as the rest of the country, but there are specific aspects here: the impact of tourism and diffuse housing on the development of urbanisation, the influence of maritime activities (fishing, the military, trade, and recreational boating in particular) on the development of port infrastructure, etc. Coastal areas also present a specific form of land take-up in the form of developments designed to protect the coastal lands from sea incursions and, more recently, to maintain foreshores to which the development of tourist activities confer great economic value.

The issues associated with land take along coastlines are also in some cases identical to those of other regions: consumption of agricultural land, fragmentation of agricultural and natural areas etc. However, they appear to be exacerbated by the limited coastal space, sensitivity to disturbance of its ecosystems and shoreline, and the effects of sea-level rise. By concentrating its development and activities on the coast, humans alter the environment and the way it functions. It is thus exposed to various feedback effects: the degradation of exploited resources, particularly fisheries or landscape resources, the relocation of certain activities and populations traditionally established on the coast, the increased exposure of developments and populations to coastal risks etc.

Definitions of the coast

As a natural environment, the coast is an interface which is subject to influence from the land, the sea and the atmosphere, all of which determine its morphology. It is usually broken down into three zones: the subtidal zone, where the extension towards the open sea depends on the underwater morphology and which mostly corresponds to depths of less than ten metres; the intertidal zone, which occupies a small (Mediterranean) or relatively large (Channel) surface depending on the seaboard; the supratidal zone, which is emergent but subject to marine influences (storm submersion, sea spray, wind transport of sand etc.).

From a legal standpoint, the coast is defined by specific regulations that apply to it either in strips (e.g. 100 m strip of the Littoral Act, strip of 50 geometric steps in French Overseas Territories), or in zones (municipalities under the Littoral Act, outstanding areas, areas close to the shore), in order to control development. Such zones are also established offshore (300 metre strips (special police for swimming and marinas), 3 miles (prohibition of certain fisheries), 12 miles (territorial sea), 200 miles (exclusive economic zone) to regulate the use of marine resources, maritime safety or areas of national sovereignty. The coastline is also partly included in the public maritime domain, which grants it a certain form of protection (regime of fines for 'major roadways' in particular in the event of development or occupation, dumping, extraction without authorisation, or damage). A wider 'coastal zone' should be considered to take into account the functional interdependencies (environmental and socio-economic) of the coastline with its hinterland.

Box 7-1 - Analysis of the literature

The selected publications provide contextual data on coastal ecosystems, their geomorphology, their development and their management. They therefore draw on both natural sciences (geology-geomorphology, marine biology) and human and social sciences (geography, history, etc.), or law.

The scientific articles selected are either syntheses (20 articles) or case studies. Global or national, the syntheses focus on certain habitats (coral reefs, mangroves, sea marshes, etc.), or on historical or ongoing processes (subsidence of deltas, sea level rise, urbanisation and 'coastal squeeze', etc.). In particular, we sought studies describing coastal habitats, their resources, their functioning, and the impacts of human development. From this standpoint, the case studies provide specific examples of the evolution of coastlines in relation to their land take, whether through habitat destruction, alteration of hydrodynamic processes or socio-economic effects.

The selected studies concern most regions of the world: in addition to French studies, the selected studies involve the coasts of Europe (24, including a large proportion on the Mediterranean), North America and Australia (19). South America (4) and Africa (6). It should be noted that particular attention has been paid to work on the French Overseas Departments and Polynesia, in particular to investigate the possible specific characteristics of land take along these coastlines. However, the 14 articles finally selected for these regions show that, although populations and activities are generally concentrated in narrow coastal areas, land take, however exacerbated it may be, has no particularly unique characteristics other than regulatory practices influenced by local culture.

7.1. Land take in coastal areas

- **Ancient occupation and land take**

The coastline is an area rich in resources and appealing to societies. Early on, populations were able to use these resources for their food (fish products, salt) and various activities (fertilizers and other agricultural inputs, building materials, etc.). Some of these resources have become the basis for substantial and sustainable trade. Coastal climates, development opportunities and alluvial soil quality on coastal plains, combined with freshwater inflows from the hinterland, also favoured the development of coastal agriculture. The characteristics of the sites and their location account for the choice of location for activities and developments on the coasts. These factors combine to form the potential of each location, but their influence varies greatly according to social groups and the historical age.

Coastal living, however, entails significant constraints and risks, which coastal societies have long endured, before being protected by various developments. Coastal engineering thus first appeared in ancient times in the Mediterranean ports, then developed from the Middle Ages with the reclamation of shores along the North Sea coast. For many years limited by technical capabilities, the means of protection against the sea developed massively from the industrial revolution, turning humans into a major factor in coastal geomorphology.

• The present concentration of populations and activities, and their drivers

Since the end of the 19th century, coastlines have undergone both an intensification and a diversification of their land take. They are notably linked to metropolisation, the maritime focus of the world economy with consequent port development, tourism (residential and leisure facilities) and the exploitation of offshore resources, particularly energy resources (fossil fuels, renewable marine energy). Except in regions with strong environmental constraints (Arctic lands and, to a lesser extent, arid tropical coasts), coastal areas are home to large populations whose settlement is mainly due to historical factors. On a global scale, the population density on the coasts is much higher than respective national densities.

In France, coastal areas covering only 4% of the land area are home to 10% of the total population, with a density (285 inhabitants/km2) 2.5 times higher than the metropolitan average (in 2010). Coastal populations are growing faster, with housing construction pressure three times higher than in the interior. The result is greater land take: between 2006 and 2012, land take in coastal areas progressed at twice the rate compared to inland areas. In 2012, 14.6% of the territory of coastal municipalities was artificialized, compared to a total mainland France average of 5.5% (Corine Land Cover data)[22]. Except in French Guiana, coastal population density and land take are even higher in the overseas departments. However, they decrease rapidly towards the interior because of the rugged terrain or, as in French Guiana, the presence of tropical forest and the absence of communication routes.

• Coastline-specific development

Coastal development (and associated structures) meets the needs of maritime economic activities (fishing, seaside tourism) or are favoured by favourable geographical conditions (trade, agriculture), and includes associated urbanisation (housing, transport infrastructures). (Table 7-1). These developments are generally accompanied by protective installations against the sea. This protection takes the form either of a line of defence located in front of, on, or behind the coastline, based on hard structures (walls, pierced walls, riprap) or 'soft' structures (beach nourishment or stabilization devices), or natural or partially developed buffer zones.

Use	Type of structures
Port activities	Quays, slipways, port protection works (jetties, wharfs)
Reclaimed or protected land	Seawalls, locks, embankments, encroachment buffer for reclaimed or protected land (agricultural, industrial, urban or infrastructure such as airports
Transport infrastructure	Coastal roads, bridges, viaducts
Tourist developments	Hotels, seaside resorts, marinas, harbours
Coastal urbanisation	Walls, stone-coverings, waterfronts, footpaths
Protective structures against the sea	Walls, seawalls, embankments, riprap, groynes

Table 7-1. Types of land take specific to the coastline

• Productive but fragile ecosystems

At the interface between land and sea, unique ecosystems are established, capable of withstanding harsh and changing conditions such as salinity, emersion/immersion by the tides, exposure to hydrodynamic agents, sediment mobility, etc. These ecosystems, particularly salt marshes, mangroves and coral reefs, are among the most productive on the planet, notably in their function as habitats for numerous plant and animal species. As buffer zones between terrestrial and marine areas, they play a major role in maintaining the overall ecological and hydrological balance. For example, coastal wetlands are important breeding and nursery areas for many marine species and provide a filtering and purification function for inland waters while

[22] The ThreeME model was jointly developed by OFCE and ADEME. See in particular "The dynamic and long-term properties of the ThreeME model", OFCE Review No. 149, 2016.

mitigating the effects of marine swells on the coasts. The destruction of coastal ecosystems is therefore likely to have drastic impacts on hydrological cycles, habitats and fish populations.

These coastal ecosystems, rare on a global scale, are directly affected by the artificialization of the spaces they occupy or their use as natural dumps, but also, indirectly, by the hydro-sedimentary consequences of nearby developments, and by pollution from industrial or domestic, land-based, river or coastal sources (Box 7-2).

Box 7-2 - Two threatened tropical coastal ecosystems: mangroves and coral reefs

Mangroves (coastal forests in humid tropical environments) are one of the most threatened habitats on the planet: they still occupy 170,000 km^2 worldwide, but land take, notably through land clearing for aquaculture, agriculture and urban development, has reduced their surface 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 remain at risk from forestry, agriculture and aquaculture. Moreover, the decrease in freshwater inputs and their quality (pollution, salinity) leads to their decline. However, urbanisation, tourist and residential developments, and industrialisation are the main factors of deterioration.

Coral reefs are also threatened ecosystems: in the early 2000s, 30% of the world's 300,000 km2 of coral reefs were considered degraded, and their area had been reduced by 10% in a few decades. Coral reefs are the object of direct destruction, by their mining or by their smothering during developments such as the construction of ports or marinas. Particularly sensitive to turbidity and water pollution (river and coastal), corals are also affected by all types of development as well as tourism. 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.

• The different trends at work

• Certain coastal sectors located in (ultra)remote areas and/or with climatic (côte aux vents in the overseas territories) or topographical (coasts with cliffs, maritime marshes) disadvantages, remain protected from significant land take, and may remain valuable areas for conservation, or for ecological or rural tourism, albeit somewhat marginally.

• Along the coastlines under land pressure, only those activities that generate added value or have a sufficiently high value to compete successfully with urban, tourist, industrial or commercial uses are able to persist, such as market gardening, viticulture, sites with a high environmental or cultural heritage value, etc.

• However, on most coasts, traditional activities, especially primary ones, are struggling to compete with the establishment of new activities that generate much higher profit margins in the short term. This situation is particularly unfavourable for activities that require large areas and a coastal location (fishing and especially aquaculture).

These trends are all exacerbated in the current context of global changes, whether demographic (through the increase in coastal populations), economic (through the concentration of activities linked to the increased coastal focus of the economy), or environmental (sea-level rise).

7.2. Land take from installations to protect against the sea

These specific forms of land take on the coast, i.e. development aimed at protection against the sea, have both intentional and unintentional impacts on the physical environment and ecosystems. These impacts occur at several scales, because the flows linked to the dynamics of coastal environments can spread the effects over some distance.

7.2.1. The developments and their effects

The coastline is an open, dynamic and complex hydro-sedimentary system. On sandy, unstable coasts, most sedimentary components are inherited from past processes, but sediments are constantly rearranged by hydrodynamic agents (currents and especially waves) or winds. The resulting evolution depends on the local sediment budget (Box 7-3), which artificialization can or aims to modify.

Box 7-3 - The sediment balance of unstable foreshores

The sediment balance quantifies sediment production, transport, accumulation and disposal over a defined time period (Figure 7-1). Sediments (mud, sand or pebbles) come from land inputs fed by continental erosion and transported by rivers, and from marine inputs, composed of detrital materials from the continental shelf or produced by marine organisms. These sediments can be remobilized by coastal (longitudinal) drift and coastal currents. This transport is carried out within the limits of hydro-sedimentary compartments, independent of each other, and delimited by natural (headlands, river mouths) or anthropic (groynes, port jetties) discontinuities of the shoreline. Materials can also leave the littoral zone under the effect of wind transfers feeding the dunes, or by dispersion towards the sea by currents.

If the sediment supply to a compartment exceeds the capacity of the hydrodynamic agents to disperse it, accumulation occurs, resulting in shoreline advance. Otherwise, the shoreline is eroded and cedes land to the sea. If the budget is balanced, the coastline experiences dynamic stability around an average position, i.e. permanent remodelling under the effect of hydrodynamic agents.

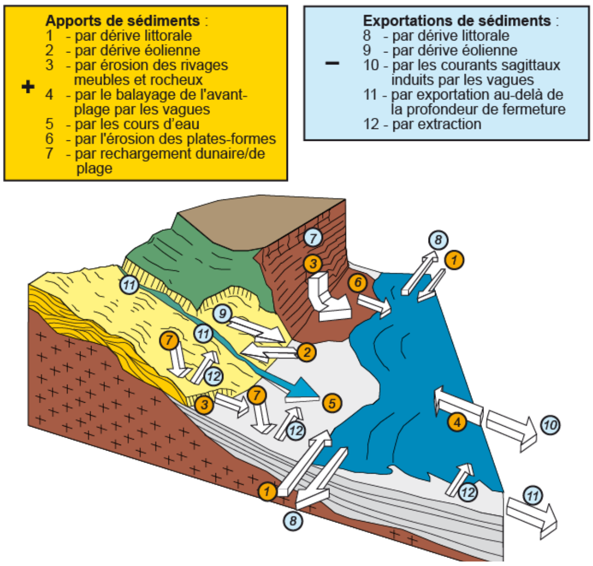


Figure 7-1. The sedimentary budget of an unstable foreshore in a temperate region (author: A. Hénaff)

- **The worsening erosion of beaches and dunes**

According to a 2004 study of coastal erosion in Europe, 70% of the beach shelf is being eroded, 20% is stable and only 10% is advancing. This situation is the result of natural changes, the abundance of sediment inherited from inputs linked to the Flandrian transgression[23] having given way to a shortage, but human interventions aggravate this sediment deficit.

Three types of artificialization combine their effects:

- The artificialization of watercourses, with the construction of numerous dams that trap their coarse load (sand, pebbles), causes a sediment shortage, which can be locally compounded by extraction of aggregates in river beds or on coastal seabeds;

- Longitudinal artificialization (by walls or rockfill) disturbs the dynamic balance of the coastline and accentuates beach slimming, which especially occurs during erosive winter weather events;

- Transverse artificialization (by groynes or jetties) blocks longshore drift and promotes the erosion of compartments located downstream of the diversion, due to a lack of sediment supply.

The combined effects of this lack of sediment supply and coastal drift are reflected in an increase in coastal erosion. To combat this phenomenon, a new series of successive installations are generally put in place, which only postpone erosion downstream, until the shoreline is completely artificial. This does not prevent the erosion of the beaches, which can continue until they disappear. The implantation of static structures in (coastal) systems in dynamic equilibrium thus proves to be scientifically nonsensical.

Similarly, coastal dune systems, whose origin dates back to the last glaciation (about 12,000 years ago), may experience erosion and regression. If the dune can no longer retreat due to development or urbanization, it may be lost.

- **The subsidence of deltas**

[23] The Flandrian transgression, due to the melting glaciers, corresponds to a sudden rise in sea level, the equivalent of which has not been recognized during geological time, so much so that we do not know any estuarine form fossil. (Source: Encyclopaedia Universalis).

Given that sediment inputs associated with the erosion of forest and agricultural soils have in the past contributed significantly to coastal sediment supply, the artificialization of watercourses by dams, and water consumption by irrigation, are currently the main determinants of the subsidence of 70% of the world's deltas. The sediment load of the Danube has been reduced by 30%, and that of the Ebro by 95%. This reduced supply of fluvial sediments can no longer ensure the natural accretion of many deltas, nor even compensate for their natural subsidence due to compaction under the effect of the weight of accumulated sediments. This phenomenon is often aggravated by protective structures against the sea and by aquaculture developments, but also by overexploitation of aquifers, drainage, or extraction of fossil fuels, and by the depletion of mangroves that retained sediments.

- **Reclamation of coastal wetlands**

The reclamation, or gradual containment of coastal wetlands to promote sediment trapping and accelerate natural accretion, first developed on the shores of the North Sea, before spreading worldwide. Initially practised for the benefit of agriculture, aquaculture and salt-making, from the 19th century it was mainly carried out for urbanisation and economic development, for which it provided cheap land and avoided conflicts linked to encroachment on agricultural land. Large cities such as Amsterdam, Venice, Tokyo and Jakarta have expanded over ancient sea marshes. The installation of port infrastructure and large industrial plants has also been an important factor in reclamation. In the Seine estuary, between 1834 and 1978, intertidal areas fell from 130 km2 to 31 km2. On a global basis, 67% of marine wetlands have been reclaimed during the historic period.

- **Increased risks due to the effects of climate change**

Rising sea levels exacerbate the shrinkage of the intertidal zone. The 'stabilisation' of the coastline by longitudinal structures of the wall or rockfill type, by preventing the 'retreat' of sandy foreshores and dune formations, no longer allows them to adapt to the rise in sea level, and exposes them to erosion. The same is true in reclaimed wetlands, where intertidal mudflats, located in front of dykes, tend to recede. These changes, which put subtidal and supratidal environments in direct contact, alter the succession of habitats that underpins the productivity of coastal ecosystems. Locally, the rate of decline of the foreshores and marshes may be such that their disappearance is feared in the short term. At the global level, rising sea levels could lead to a 70% loss of coastal ecosystems (coastal wetlands, mangroves) by the end of the century.

7.2.2. Dynamic coastline management options and 'soft' methods

Faced with the risks associated with sea level rise, four scenarios for the adaptation of coastal developments are typically considered:

a) **Doing nothing** is a baseline rather than a seriously considered option as its long-term cost is likely to be very high;

b) **Holding,** by strengthening coastal defences, is the option envisaged in the most heavily developed areas, which are therefore technically, financially or socially difficult to relocate. On coasts with very high population growth, such as deltas or coastal megacities, this choice will probably require extensive installations and drastic measures, without however eliminating the risk;

c) **Advancing**, i.e. artificialising the foreshore by advanced breakwater-type protection or by reclamation, in order to increase the distance between existing assets and coastal hazards, is envisaged in high-stake sites. This 'line of defence' option is being applied in the Netherlands (Delta Plan). But at what ecological cost?

d) To make a **strategic retreat**, by creating buffer spaces between human assets and the sea, notably through the rehabilitation of coastal wetlands. In the case of reclaimed agricultural areas or undeveloped coastlines, where the implications remain moderate, this strategy is generally considered the best by managers, especially as it would allow the development to be rebalanced in favour of the hinterland. But it encounters a reluctance to abandon hard-won land on the sea, as well as the self-interest of landowners.

It is recommended to favour 'soft' methods that aim to adapt to the evolution of the coastline (building with nature), by favouring a dynamic stabilisation rather than 'holding nature back' at any price. The ecological engineering techniques used are similar to the artificial and continuous maintenance of the operation of hydro-sedimentary systems. In theory, the benefits of dynamic coastal management are multiple: improved resistance to marine erosion, conservation of ecological values, and lower cost than for fixed protection. The viability of this option depends on the natural processes to be managed, but also on its integration into the overall management process.

7.3. Unique characteristics of coastal urbanization

7.3.1. Socio-economic determinants

• Older urban settlements

The geographical determinants of these locations are well known. On a local scale, the characteristics of the site (linked to its topography, its hydrography, its health etc.) can favour defensive or harbour functions, or allow the bulk transfer of goods between land and sea, as in the case of sheltered bays or estuaries. For example, in the former West Indian colonies, the establishment of towns on coastal plains and at the mouths of rivers was intended to facilitate trade. At the regional level, the quality of the site depends on its strategic location in relation to access to fishery and land resources, to navigation and trade routes, or to the surveillance or control of a territory. The rise of the great ancient thalassocracies (Athens) or medieval thalassocracies (Venice, Hanseatic League) thus rested on the control of the great sea and land trade routes.

These historic sites may have been disrupted or reinforced by the economic and demographic changes brought about by the industrial revolution and by the societal changes that accompany them.

• Coastal urbanization and metropolisation

In most countries with a coastline, the main cities (over 100,000 inhabitants) are located by the sea. These populations were gradually concentrated in ancient or medieval port cities, as in the Far East, in the Mediterranean basin, and around the Baltic or North Sea. In other regions, a large proportion of coastal cities owe their origin to colonial expansion and trans-oceanic migration, essentially European between the 16th and early 20th centuries, whether to America, Australia or South Africa, where large cities were founded from scratch (Rio de Janeiro, Boston, Sydney etc.). Simultaneously, the ports of metropolitan France benefited from the colonial boom, through the creation of military bases (Brest, Lorient, Le Havre, etc.) and through the trade in overseas wealth (Seville, Hamburg, Amsterdam, etc.). Indeed, most major coastal cities, and in particular dominant metropolises such as London, New York and Tokyo, owe some of their power to their past or present maritime traffic.

The lack of space, and competition with other infrastructure (ports for example) can, according to the sites, push land take downstream and to the sea, or inland. Cities have thus encroached on the sea, in the form of floating districts (Hong Kong, Bangkok) or reclaimed land (Sydney, Hong Kong, Papeete airports).

• Tourism and holiday resorts from the 20th century onwards

On all coastlines with landscape or seaside amenities, tourism is one of the main factors of land take. Its rather recent development stems from changes in society's tastes, rising household incomes, longer free time (paid holidays, reduced working hours, retirement) and the rise in mobility. The 'desire for shore' is based on the specific amenities of the coastline, whether climatic (the benefits of the sea air, sunshine), landscape (the aesthetics of the sea view) or seaside and recreational (nautical activities).

The expansion of tourism from the 1920s onwards led to the development of several generations of seaside resorts, generally the result of heavy and planned operations (such as the Plan Racine on the Languedoc coast). These resorts then formed diffuse and poorly supervised urbanisation hubs. Initially, seasonal tourism development (outdoor camping, caravanning, straw huts) tends to become more or less legal. The poorly controlled construction of second homes results in a high consumption of space and urban sprawl, at the expense of agricultural and natural areas, as well as a loss of the aesthetic qualities that initially drove the tourism.

• Residential choice and diffuse urbanization

Even more recently, the same factors (rising incomes, emergence of new habits, increased leisure time, development of major transport infrastructure, etc.) have combined with the search for a quality living environment and the possibilities of remote work offered by new information and communication technologies to change residential choices (see Chapter 5). The coastline is not the only area to be affected by these relocations, but it combines all the prerequisites for attracting pensioners, as well as working people motivated in particular by the practice of water sports (boating, surfing).

The resulting urbanization generally follows several stages: a phase of urban sprawl, through the uncontrolled proliferation of individual constructions outside the urbanized nuclei and as close as possible to the coast; a stage of better organized urbanization, through the construction of housing estates; and finally a phase of implementation of regulatory measures to affect the right to develop in certain zones and to protect areas considered outstanding.

7.3.2. Socio-economic impacts

The recent diversification and intensification of coastal activities is reflected in increased land take, which exacerbates competition with activities historically established on the coast (fishing, aquaculture and especially agriculture) and with existing local populations.

- **Land pressure**

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 heritage of the market garden land structures specific to the coastline.

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.

- **Economic or social displacement of local populations**

The permanent population may suffer from this land tension, through the appropriation of the coastline by the wealthiest socio-economic groups, with the resulting rise in prices and even land speculation. In France, land buyers by the sea are both wealthier (over-representation of the upper socio-economic category) and older than for France as a whole; retired people represent 11% of land buyers, i.e. double the metropolitan average. People on the lowest incomes, especially young people, cannot compete. They often have no other residential choice but to move back to the hinterland, where land and real estate are more accessible.

This situation is exacerbated on the coastlines popular with high-income tourists, who invest massively in real estate. The effects are then both demographic (ageing and seasonal variation of the population), economic (increase in land values and speculation) and social (appropriation of the coastline by the wealthiest categories, relegation of others). The costs generated by the over-servicing of tourist resorts, often calibrated for summer peaks, increase local taxation and can further aggravate demographic decline.

In developing countries in particular, the increased fragility of coastal communities can also result directly from the alteration of natural environments and the resources from which they benefited for their survival.

- **Ecological and Landscape Feedbacks**

In many coastal regions (especially Mediterranean and island regions), the increase in the urban and tourist population leads to increased water consumption, which when exceeding its renewal capacity can lower the level of coastal aquifers which are then exposed to salt water intrusion. This deterioration in water quality, which poor effluent management can also aggravate, exacerbates use conflicts with activities that require good quality fresh or marine water, such as aquaculture or seaside tourism.

Poorly controlled urbanization contributes to a landscape degradation of coasts, by the use of ugly or boring urban and architectural forms, and by the messy landscapes created by urban sprawl and fragmentation of areas. In coastal tourist resorts, these alterations remove some of the aesthetic and recreational value that originally underpinned their use.

- **Increased risks due to the effects of climate change**

In response to repeated disasters, some regions are more rigorously planning their urbanization to integrate these risks. When this is not the case, population groups that can afford it start to relocate to sites that are less exposed to risks, thus triggering new land dynamics that tend to reinforce urban sprawl, but also social inequalities. Indeed, when the population does not have the means to adapt and the authorities are inactive, reconstruction takes place at the scene of disasters, without significant adaptation. In fact, these disasters are not 'natural', but are the result of an indiscriminate exposure of human and property interests to hazards (tsunami, marine surges) due to careless coastal development.

The coastline is particularly vulnerable to the aggravating effects of ongoing climate change. In their most pessimistic scenario, Neumann et al (2015) estimate that the population exposed to coastal hazards in low coastal areas (1 in 100-year inundation zone) could increase from 189 million in 2000 to 411 million by 2060.

7.4. Unique characteristics of coastal governance

Along coastlines, as elsewhere, the policy of laissez-faire has long dominated, leading to land take with little control, and structured by land availability and geographical factors such as proximity to the coast, urban centres and roads, or topography. This situation still prevails in many countries, particularly in the developing world.

- **The introduction of regulations**

Developed countries, but also countries with particularly desirable coastlines such as along the Mediterranean, have adopted specific coastal legislation. They are based on the implementation of similar principles: the delimitation of areas which cannot be developed (not to be built), development to be perpendicular to the coast (known as 'at depth'), and the protection of green corridors, in particular through the definition of outstanding areas. In France, the Littoral Act of 1986 incorporated these principles into town planning law, but its effects remain mixed. This law also created the mechanism for protecting so-called 'outstanding' areas by restricting their use and preserving their harmony and integration into the landscape.

In addition, because of the environmental quality of some coastal areas, traditional environmental laws are especially applicable. They may be the result of international conventions (UNESCO, Ramsar, etc.) or of national legislation. For example, there are national parks (Port-Cros), nature reserves (Camargue) and marine nature parks (Côte d'Opale). Moreover, since its creation in 1975, the *Conservatoire de l'espace littoral et des rivages lacustres* has pursued a land acquisition policy aimed at protecting the 'natural third' of the French coast (as of 2017, it owns 13% of it).

The overseas territories are subject to the same laws as mainland France (Littoral law, Landscape law etc.), while being adapted from a jurisdictional standpoint, but the difficulty lies in their application to local, social and environmental circumstances. This is the case in **Mayotte**, where customary Muslim rights and common law coexist in land legislation, but 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 of the Littoral Act are superimposed on those of the 50 geometric steps zone (81.2 m), which is subject to specific legislative, natural and socio-economic and heritage characteristics.

- **Regulation may not always be effective**

These measures have often been introduced or applied too late (sometimes due to political and administrative weaknesses) in view of the rapid and largely spontaneous dynamics of coastal land take. Moreover, tools often remain at the service of promoting economic development rather than environmental protection. In fact, urban planning is often accused of following spontaneous trends after the fact and distributing building rights by adapting zoning and regulations, instead of being a genuine planning tool. In addition, the multiplicity of regulations results in overlapping management boundaries. A review of the Littoral law published in 2007 made a mixed finding regarding its application. While it did not question the legitimacy of a specific coastal policy, on the contrary, this assessment pointed to shortcomings in its application and called for a review of certain provisions. Numerous conflicts exist around this issue between the various stakeholders, and 10 years after this assessment, a reform document has been proposed but without any outcome.

Indeed, even where regulation exists, it has a less influential structuring effect than conventional economic factors (Box 7-4). The effects of the regulations thus appear to vary, between encouraging and constraining urbanisation, protecting the environment and abandoning agriculture, 'freezing' the development of coastal areas and shifting urbanisation to the hinterland.

Zoning established for urban planning or environmental protection contributes to the increase in land prices by restricting supply, and by the additional value conferred by amenities, especially landscapes, linked to protected natural areas. The effect of regulations is equally mixed. The property tax exemption law (Pons law, 1986) applied in the overseas departments has, for example, resulted in a dual phenomenon of fragmentation and land speculation, thus affecting agricultural and natural areas.

Box 7-4 - The example of Pays de Brest

Although disputed, the effects of coastal protection can prove effective, as the example of the Pays de Brest shows. The first figure (Figure 7-2) shows the land acquired by the Conservatoire du Littoral in Pays de Brest. 23% of the land on the coastal strip (0-100 m) is now excluded from urbanisation: the objective of the Tiers Naturel has not yet been achieved, but it is now within reach.
Indeed, construction on the coast is indeed increasingly restricted, even outside these protected areas. The initial attraction exerted by the coast, in the absence of protective measures, tends to diminish considerably as soon as regulations are put in place. The second illustration (Figure 7-3) shows the evolution of land parcel status between 1968 and 2009. It shows that, since the mid-1970s, residential construction has been increasingly restricted on the shoreline. The analysis carried out confirms that the regulatory measures (laws and urban planning documents) have effectively reduced the risk of construction on parcels within the 100 m coastal strip by half.
The proximity of infrastructures (roads, services) or pre-existing built-up areas now have a much more decisive influence on residential construction than proximity to the sea.

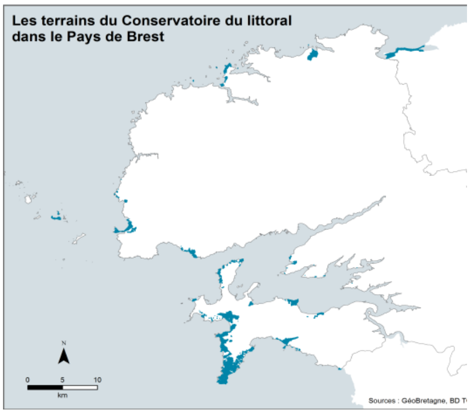


Figure 7-2. CEL land in Pays de Brest (source : GéoBretagne)

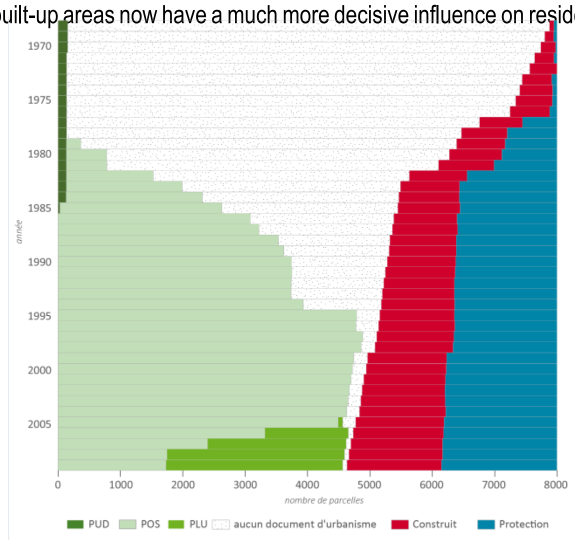


Figure 7-3. Changes in the status of land parcels in Pays de Brest within the 100m coastal strip between 1968 and 2009

- **The need to implement Integrated Coastal Zone Management (ICZM)**

ICZM is a public policy tool that the European Council has been promoting since the 1970s. In particular, it was the subject of a European Union recommendation in 2002, but one must admit that its implementation is still not effective. ICZM would, however, make it possible to deal with the sectoral regulations that apply to the coastline by having an integrated approach to terrestrial and aquatic elements, and by taking into account the exploitation of resources within environmental protection objectives. Although ICZM aims to apply the principles of sustainable development, it is difficult to achieve because of the profound divergence of interests between coastal users, and also because responsibilities are spread across different institutions at different levels, resulting in the dilution of responsibility.

7.5. Conclusions and policy tools

The land take of coastal areas thus responds to the drivers that exist throughout France, but these drivers are increasingly powerful. The same applies to environmental impacts, but which have specific characteristics. On the other hand, and perhaps surprisingly, coastal issues in the Overseas Territories are not markedly different from those found in mainland France, at least in regard to threats from development. However, biodiversity richness, vulnerability to climate change and societal differences call for specific policy responses. The artificialization of the coastline needs to be better understood, both in terms of its extent and its impacts.

Measuring land take in coastal areas. At a local scale, field observation, temporal analysis of aerial photographs or very high resolution satellite images, and their comparison with ancient iconography (maps, photographs, and paintings) make it possible to precisely observe the evolution of coastal landscapes, including in its most diffuse forms. But for larger territories, analyses must use images with lower spatial resolution, allowing only the identification of the most obvious and extensive forms of land take. The diffuse urbanisation, so widespread on the coast, then remains undetected, as are the effects of recreational activities practised in natural areas without specific infrastructure. The actual extension and artificialization of the coastline therefore remains difficult to measure.

Differentiating the impacts of artificialization. Some environmental alterations result from complex combinations of factors that make it difficult to establish causal relationships. The evolution of wetlands, for example, depends both on natural causes (accretion, subsidence) and on direct (drainage, embankments and reclamation) and indirect (artificial catchment areas, pollution) anthropogenic causes.

Environmental restoration capacity. Field studies have shown that some coastal ecosystems have a high resilience following stress, but there are also many cases of coastal environments that have not withstood their artificialization. The difficulty then consists in determining whether the lack of resilience is due to intrinsic fragility or to overly severe disturbances.

Evaluation of the costs and benefits of artificialization. The consequences of artificialization are by no means always negative. For example, tourism development can be a source of new economic income for the local population, or even a factor in protecting the environment and coastal landscapes when they are regarded as a tourist resource. In this context, the evaluation of the costs and benefits of artificialization is a useful governance tool. Usually carried out by economists, these studies rely in particular on hedonic pricing methods (or users' willingness to pay for a particular service offered, notably by the environment) or valuation of ecosystem services. However, these assessments remain complex to carry out and therefore difficult to disseminate to all stakeholders involved in managing artificialization. The main reservations that their opponents have about them are both conceptual (can the environment be assessed in monetary terms?) and methodological (how to ensure that the assessment is exhaustive and objective?).

8. Avoiding or reducing land take, or compensating for its effects

As the subject of intense political concern and considerable public debate, land take covers, as discussed in the previous chapters, an extremely multifaceted economic and social reality, making it difficult for scientists to grasp. By definition, artificial land, whatever their cover, are the surfaces on which all human activities take place (except agricultural and forestry activities). As land for housing, businesses, public services, transport infrastructure, etc., it provides many services to society. All of these activities tend to be concentrated in cities which, in recent times, have spread either by pushing back their borders, or by the 'peri-urbanisation' of more distant and discontinuous areas with the city itself. At the same time, land take results in environmental effects, which vary according to the degree of soil sealing and the local arrangement of soils with different covers, and on agricultural (and forestry) activities competing for the use of the same soils and/or spaces. The limiting of these different effects probably occurs in different ways depending on whether the use is residential, economic or infrastructure, and whether the land in question is located in the city centre or in the dense suburbs (where the soil 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 (and in particular tourism). Thus, determining whether to limit the extent of artificialized soils and where this should be achieved, while preserving the economic and social services these soils provide, 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 reduce 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 them reveals the imprecise and multifaceted nature of the concept of land take. Strongly linked to spatial planning policies, 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 cities and, in particular, the socio-economic profiles of neighbourhoods. Through the various elements studied in the course of this review, policy instruments and legal tools have emerged. This chapter therefore aims to summarise them, but also to give a legal and fiscal interpretation. This analysis has revealed 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 (8.2), the second is to reduce its impacts (8.3), while the third, less established than the two previous ones, offers prospects for compensating for land take (8.4). Firstly, however, the legal and fiscal pathways to land take are presented (8.1).

8.1. The legal and fiscal drivers of land take

An initial assessment reveals that, as a consequence of the lack of precise identification of the subject of 'land take', public law and policies (8.1.1) and taxation (8.1.2) have elements that directly or indirectly encourage land take, or more precisely, urbanization.

8.1.1. The legal drivers of land take

Land take is inseparably 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 is no regulation which opposes it, or on the contrary, that this regulation favours it and that the regulation is accompanied by financial and fiscal mechanisms likely to impact real estate markets.

• The tightening 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 the litigation law, **either to restrict the ability of applicants to appeal against a document or an urban planning permit, or to allow the judge to formalise it**. For the most part:

The petitioner, appeal deadlines and power of regularisation 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 statutes 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 conditions have been tightened, and the applicant will now need to demonstrate how they are directly affected.

- Recent legal changes also 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 the judge is increasingly empowered to regularise the said documents as well as the building permits, which increasingly allows him to prevent their annulment (C. Urb. Art L. 600-9 and 5).

Restrictions on 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 work). Following the 'Pelletier' report in 2005 and the 'Labetoule' report in 2013, two reforms will make this regime more complex and limit its scope. The demolition of buildings is now limited in time (6 months or two years in certain protected areas) and its conditions are regulated so as to limit its application.

• Housing construction: a constraint for communities

Certain provisions impose construction and thus lead to land take. The local housing programme (PLH) requires intermunicipalities to implement a local housing policy in order to meet housing and accommodation needs and to promote social mixing and urban renewal. This programme aims to balance housing 'responsibilities' between the municipalities within an intermunicipality and thus distribute the obligation to artificialize land, if the project land base was not already built. Although urban renewal actions and operations are not formally encouraged, they are not prohibited.

Some ways of reducing land take could be envisaged, at the cost of minor modifications to this programme: linking aid and subsidies to the land economy, involving a prioritised search for land recycling and the submission of a report establishing the situation in the municipality's or intermunicipality's territory; and priority given to urban renewal operations, under the same criteria of demonstration of land availability.

Box 8-1 - 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 (36.5% in Southern Corsica, 34% in Upper Corsica and the Alps, compared with 10% of the national average). The regulations do not, however, limit its construction, let alone prohibit secondary uses of a building that has been built as a principal residence.

Other countries have opted for a more radical solution, such as banning second homes once a certain ratio has been exceeded. This is the case in Switzerland, following the adoption of the Weber initiative (Federal popular initiative 'to put an end to the invasive construction of second homes'). Thus, the federal law on secondary residences of 20 March 2015 prohibits their construction in municipalities that already have more than 20%, or would have more than 20% if the requested building permit were granted.

• The incentive effect 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, in particular whether households or enterprises relocate to targeted areas. They do not address whether or not they contribute to urban sprawl. These evaluations highlight the difficulty of countering the mechanisms at work on the real estate markets and, in particular, the trends toward segregation and urban sprawl.

The impact of the SRU law. The SRU law of 2000 has the objective of achieving 20% of social housing in agglomerations of more than 50 000 inhabitants. It has had a significant positive effect on the growth of social housing, 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 enactment of the Méhaignerie Act in 1986 (aimed at promoting rental investment, accession to ownership of social housing, and the expansion of land supply), with the aim of encouraging households to invest in new rental housing by granting them tax credits. The Scellier law in 2009 excludes the denser areas that are under less stress. Studies, however, show that these schemes would not have increased housing production but would have led to a 1% price increase in the areas close to the boundary between the areas included and excluded from the scheme.

The inflationary effect of individualised housing assistance and rent regulation. Personal assistance has grown strongly in France, particularly personalised housing assistance (APL). If construction does not increase sufficiently following an increase in housing subsidies (low price elasticity), then rents or prices will adjust upwards to balance supply and demand. It is therefore the owners who benefit from the subsidies in this case. We are, in effect, describing an inflationary effect of aid. Over the last 40 years, rents were only freely set at the time of new rentals or lease renewals during the years 1986 to 1989. Studies show the negative long-term impact of rent control on housing maintenance and expansion of supply.

First-Time Home Ownership Assistance: The Impact of the Zero Interest Loans (ZLT). Initially reserved for the purchase of new housing stock, the PTZ is currently also available for purchasing renovated existing housing. The PTZ had an inflationary effect on land prices. The analysis of these changes was conducted by comparing the growth in loans granted with housing prices at the borders between different zones, following the differentiated increase in the amounts of PTZ. The results show that the more generous conditions of interest-free lending lead banks to increase the volume of loans granted to homebuyers, and that much of this increase is reflected in higher prices.

Subsidies within specific regions. Policies targeting certain regions have been developed to deal with major regional disparities. Subsidy schemes in particular areas may be important in particular cases - for example where a disadvantaged population cannot relocate and there is no work in that region, it may then be justified to provide financial incentives for worker mobility - but these schemes are usually built into rents and recouped by landlords.
Governments usually justify this type of intervention on the basis of equity arguments, which are challenged by economists who advocate more direct means (more progressive income taxation, allocation based on wealth criteria) to reduce inequalities, and are concerned about the possible inflationary effects of targeted policies.
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 the creation of enterprises and employment is limited and temporary in relation to their significant costs. However, these policies are more effective when the areas concerned have high accessibility.

8.1.2. The fiscal drivers of land take

- **Property taxation: elements of the debate in France**

Since real estate assets account for more than half of French people's assets, any consideration of property tax adjustments forms part of the broader debate on optimal taxation of assets, including its incentive and distortive effects on other assets or sources of income. In France, the few discussions on the subject are strongly marked by a context of tensions on the housing market. The priority then should be to rethink taxation with a view to seeking tax fairness, and making this market more fluid by providing the appropriate incentives to reduce the phenomena of land banking, and increase the amount of buildable land on the market.

The withholding of buildable land is encouraged by a tax based on historical cadastral rental values of the land, which, even when increased annually, are very significantly undervalued in relation to their market value. The low taxation confers a high holding value on an investment in bare land, pushing the investor to postpone its sale for construction with the anticipation of a price increase.

Box 8-2 - 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 the size of housing leads to an increase in population density and therefore a decrease in the size 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. On average, the municipalities that took up these cases applied a very modest increase, with no real impact on behaviour. The Finance Act for 2013 systematized and strengthened the scope of property tax increases on undeveloped but buildable land provided for in Article 1396 CGI, in areas where real estate tensions are high. The aim is to encourage the release of land for housing construction. Thus, in municipalities subject to the **annual tax on vacant housing**, the rental value of vacant constructible land, after a 20% allowance, was augmented by 25% of this amount and by a fixed value set at 10 €/m^2 for taxes 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, the rental value of buildable land located in urban areas or zoned for urbanisation, 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, may be increased for the calculation of the share to be paid to municipalities and public institutions engaged in intermunicipal cooperation 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. This may involve, among other things, lowering the tax rate on capital gains on the sale of building land, abolishing deductions based on long-term holdings and abolishing onerous transfer duties.

Box 8-3 - Economic 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, in particular the Territorial Economic Contribution (CET). Another means is the provision of land at the symbolic euro rate (gifts to private individuals are prohibited). A sale at a very low cost can be justified, according to the Council of State, by job creation). However, a report by the 2014 Council for Taxation on Local and Company Taxes highlighted the fact that local taxation is only one of many criteria in the location choices of companies: the attractiveness of a territory results above all from its economic environment and the availability of land supply. This implies a land take that the community struggles to control, and at the risk of forgoing the establishment of companies 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, imposed at a single rate. 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 is based. 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 lot sizes, 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 for the State of Florida, where no impact on construction rates in central, peripheral or rural cities was observed. Finally, a study on the impact of a development tax in and around Albuquerque concludes that there is a reduction in construction on the urban fringe and growth in areas close to the city centre.

In France, this tax was introduced in 2010 and is based on the value of the construction surface area. Notwithstanding the exemption of certain buildings according to their use, and an allowance of 50% according to the characteristics of certain premises, the rate of the municipal or inter-municipal part of the development tax may be increased up to 20% in certain sectors by a reasoned decision, if the completion of substantial road works or networks or the creation of general public facilities is made necessary because of the importance of new buildings built in these sectors. **Thus configured, this tax provides little incentive to reduce ground surface use, since it was introduced in order to participate in the financing of public infrastructure in the municipality.**

This tax might, with **certain modifications**, become an incentive to reduce land use, such as:

- The introduction of variability in the development charge based on soil quality or land availability indices;
- A differentiation of the tax according to whether or not the project concerns previously undeveloped land, so as to increase the cost of projects on greenfield land. This solution may be accompanied by a reduction of the tax in urban centres and developed parcels.
  However, **two pitfalls should be avoided:** a rate that is too low an incentive (but a high rate may not have an effect on manufacturers with sufficient financial capacity) and the temptation for municipalities to use it for general revenue-raising, rather than planning for a particular use related to its purpose, or for it to be allocated to another public person.
- An exemption from the tax in the event of land recycling, a type of tax 'reward' in favour of the builder who would carry out reconstruction after demolition or after decontamination of a piece of land, thus avoiding artificialising another piece of land elsewhere.

8.2. Mechanisms to avoid or control land take

By attempting to limit the subdivision of agricultural land and to control urban sprawl, public policies and their legal and fiscal implementation present a set of tools for controlling land take, without necessarily identifying this objective precisely. Even if the control of land take is not a stated and general legal objective, the law presents tools, including the regulation of land use by urban planning law, by means of planning documents and authorisation mechanisms.

Land use through zoning mechanisms distributes land use throughout the area and appears to be the most appropriate tool to avoid land take, although in practice there are many limitations (8.2.1). Both law and taxation are more effective, or at least better defined, when they are designed to apply to particular areas such as rural areas or the coastline (8.2.2). Finally, the objective of densification, pursued by law, is a means of limiting land take, although its beneficial effects from a spatial point of view must be weighed against the resulting environmental impacts (8.2.3).

8.2.1. 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 (Figure 8-1). They also serve as a basis for spatially differentiated taxation policies, etc. 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.

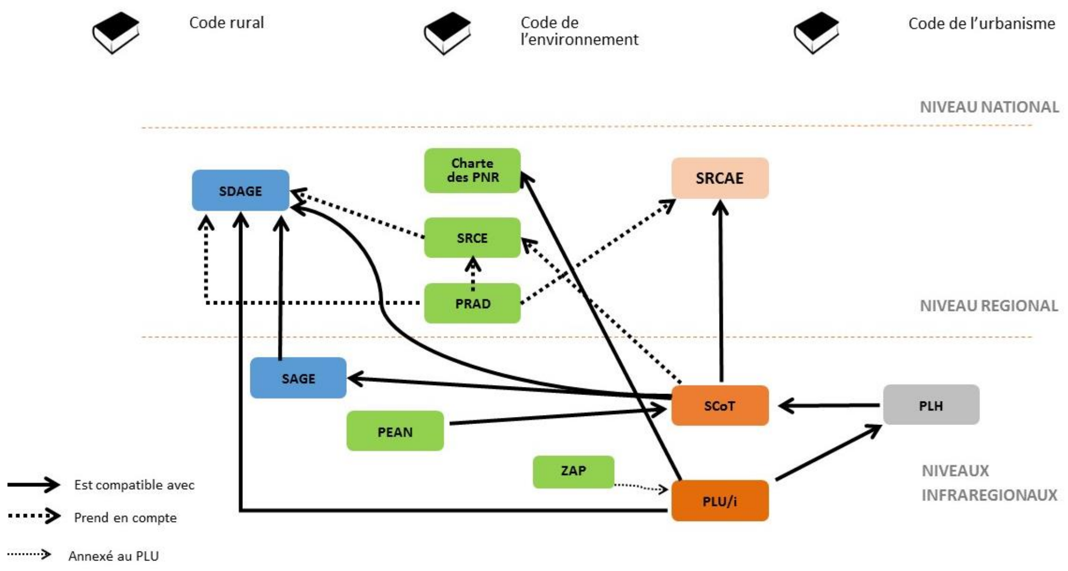


Figure 8-1 Compatibility reports and consideration of key planning documents
(PEAN: perimeters of protection and enhancement of agricultural and natural peri-urban areas; PNR: regional natural park; PLH: local housing plan; PLUi: local intermunicipal town planning plan; PRAD: regional sustainable development 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)

Between the legal tool and political application, the effectiveness of zoning to avoid land take depends to a great extent on governance. On the one hand, decentralization allows a level of local governance closer to territorial realities, while on the other hand it exposes the decision-maker to pressures and objectives that may call into question the effectiveness or relevance of the zoning.

- **Does zoning prevent urbanization?**

The measures to prevent urban sprawl are certainly in competition with those that allow land take, which are driven by other demands. For example, limiting land take by the principle of continuous construction may be undermined by the existence of a local urban plan or a communal map that delimits hamlets and continuous groups of traditional constructions or dwellings which may be expanded, taking into account the traditional characteristics of the habitat, 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, according to local circumstances, that an urbanisation which is not situated in continuity with existing urbanisation is compatible with protection of agricultural, pastoral and forest lands, with the preservation of landscapes and environments characteristic of natural heritage, and protection against natural risks.

Strictly excluded non-constructible zones (including UGB) limit urbanisation. In France, only strict environmental zoning (equivalent to IUCN categories I to IV[24]) ensures a lack of new housing over 10 years. In urban planning, PLUs/PLUIs must respect the degree of compatibility with higher planning documents, such as the Territorial Coherence Schemes (SCOTs), which limits options. On the other hand, some will be more restrictive than others and, ultimately, the administrative judge may simply verify that the intermunicipality has respected the principle of the balance between its development aspirations and the different objectives (environmental, social, etc.) for which it is responsible.

In addition, some studies show zoning policies to have a direct impact on real estate supply (availability and price) and lead to denser construction if there is no density limit. The example of the Greenbelts (see Chapter 5) shows that these belts can also push urbanisation further. The long-term effectiveness of these policies is ambiguous because they are local and there is a potential acceleration of construction in peri-urban areas. Generally, **the best results in terms of regulating new constructions come from rigid zoning, accompanied by an effective control system.**

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[24] Six categories of protected areas have been defined by IUCN. They correspond to a gradation of human interventions in natural environments, from the exclusion of any activity to sustainable biodiversity management strategies: (I) Strict nature reserve or wilderness area; (II) National Park; (III) Monument or natural element; (IV) Habitat or species management area; (V) Protected landscape or seascape; (VI) Protected area for the sustainable use of natural resources.

The fact that zoning can be used to limit the density in constructible zones limits its effectiveness in regulating land take. Indeed, a free expression of the market would lead to more densification of building areas. Once a territory is artificialized, the question is whether this density should be restrained or increased, whilst at the same time protecting the urban boundary to avoid further sprawl. The density must then be evaluated since threshold effects exist. The transfer of the right to build (Chapter 6 and see below) could be used for local densification, as well as a rebalancing of property taxes (to be increased) and housing taxes (to be decreased).

Box 8-4 - Fiscal decentralization

Most OECD countries are characterised by a high degree of administrative fragmentation[25] at the local level. When this jurisdictional fragmentation is coupled with fiscal decentralization and a lack of coordinated economic governance, the conditions are in place for competition to take hold. The latter is naturally exacerbated when local authorities have taxing power over companies, whether or not linked to the property value being used.

In Italy, decentralization of property tax (ICI) has encouraged local governments to increase (not reduce) building permits in order to broaden their tax base and compensate for the concomitant decrease in state remittances. In other words, here the allocation of property tax to municipalities allows the use of accommodative land planning as a variable for budgetary adjustment. Entrusting the same local authority with the power of taxation and land regulation, which amounts to being able to define the tax base, can lead to an increase in new constructions.

Zoning may have an effect on prices, but this is not clearly established. It is necessary to distinguish the supply of land from the supply of buildings and, to the same extent, artificialized land from 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 landowners can anticipate regulatory change by subdividing their plots or negotiating with decision-makers. If the zoning does not provide for building density limitations, then price increases may lead to denser building forms.

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

- **Governance of land take and evolution of zoning**

There is a trend towards the grouping of municipalities and the coordination of their urbanisation around the SCOTs, at the same time limiting the possibility, for those who abandon them, of opening up to urbanisation natural areas and areas of future urbanisation. However, a set of criteria of distance, population agglomeration and various geographical considerations limit this regime.

The ALUR law renews the mechanism by giving it another philosophy: to avoid urban sprawl in municipalities which are not covered by a SCOT (or in certain cases, the planning schemes for the overseas regions, the SDRIF (cf. Chapter 6) and the Corsican planning and sustainable development plan take the place of the SCOT).

The following are affected by a restriction on opening up to urbanisation: areas to be urbanised with a PLU adopted after 1 July 2002; natural, agricultural or forest areas in communes covered by a PLU and areas identified in municipal maps as not buildable. Furthermore, 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 establishment may 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 determinants of zoning changes explain the dynamics of urban sprawl. The dynamics of Urban sprawl respond to two scenarios:

In the first, zoning is highly influenced in the medium term by individual preferences, but in the long term the determinants of residential conversions and prices are the main drivers of urban sprawl. In the second scenario, conversely, if local governments steer urbanization by favouring public interest objectives rather than simple re-election and thus free themselves from the influence of owners and developers, zoning can follow its own dynamics.

In rural areas, these changes are mainly made by extending zoning, with a strong dependence on the existing secondary road network. Furthermore, **the scale of decentralization** is crucial: the finer the scale, 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 fiscal resources. This phenomenon can be observed in France both in peri-urban areas and in areas of agricultural decline. In

[25] Indeed, in OECD countries, metropolises with more than 500 000 inhabitants comprise 74 municipalities on average.

reaction, several French laws (SRU 2000, Grenelle II 2010, ALUR 2014) have initiated a movement of recentralisation: the implementation of SCOT responds to this logic and even more so the PLUi.

8.2.2. Avoiding land take in certain specific areas

There are many provisions to protect land against land take, whereby some areas are better protected than others, especially when they are used for production. The taking into account of soil characteristics in urban planning documents can allow 'reasoned' land take and, since it cannot always be avoided in the context of planning based on environmental assessments, one must accept that its effects must be compensated for (see below).

• Protection of mountain and coastal areas against land take

In addition to the specific case of protected areas (national parks, nature reserves, etc.), urban planning law makes it possible to protect certain areas, including mountain areas and in particular the land necessary for the maintenance and development of agricultural, pastoral and forestry activities (urban law, 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 countries, but also countries with particularly desirable coastlines such as along the Mediterranean, have adopted specific coastal legislation. They are based on the implementation of similar principles: the delimitation of areas which cannot be developed (not to be built), development to be perpendicular to the coast (known as 'at depth'), and the protection of green corridors, in particular through the definition of outstanding areas. In France, the Littoral Act of 1986 incorporated these principles into town planning law, but its effects remain mixed. This law also created the mechanism for protecting so-called 'outstanding 'areas by restricting their use and preserving their harmony and integration into the landscape.

Urbanization around water bodies. The natural sections of the banks of natural or artificial water bodies with an area of less than one thousand hectares are protected over a distance of 300 m from the shore; all new constructions, installations and roads are prohibited as well as all excavation and scouring (L. 122-12 - for water bodies of more than 1,000 ha, the Littoral law applies, the distance being then reduced to 100 m). However, the small size of some water bodies may justify the non-application of this system. However, certain constructions are permitted in these areas, when linked to agro-sylvo-pastoral production or to the activities of the premises (lodgings, camping, reception and safety equipment, etc.) (L. 122-13). Other constructions and installations may be allowed by dispensation, depending on local circumstances.

The restrictions on the extension of urbanisation to areas close to the banks of inland water bodies subject to the Littoral Act should be justified and explained in the local town plan, 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 (Littoral law, Landscape law etc.), while being adapted from a jurisdictional standpoint, but the difficulty lies in their application to local social and environmental circumstances. This is the case in Mayotte, where customary Muslim rights and common law coexist in land legislation, but 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 of the Littoral Act are superimposed on those of the 50 geometric steps zone (81.2 m), which is subject to specific legislative, natural and socio-economic and heritage characteristics.

These coastal measures have often been implemented too late (sometimes due to political and institutional weaknesses) in view of the rapid and largely spontaneous dynamics of coastal artificialization. Moreover, tools often remain at the service of promoting economic development rather than environmental protection. An assessment of the Littoral law published in 2007 made a mixed finding regarding its application. While it did not call into question the legitimacy of a specific coastal policy, on the contrary, this assessment pointed to shortcomings in its application and called for a renewal of certain provisions. Numerous conflicts exist around this issue between the various stakeholders and 10 years after this assessment, the reform of coastal laws is an opportunity to better to protect the coastline against land take.

Box 8-5 - Towards an integrated coastal zone policy: Integrated Coastal Zone Management (ICZM)

ICZM is a public policy tool, which the European Council has been promoting since the 1970s. In particular, it was the subject of a European Union recommendation in 2002, but one must admit that its implementation is still not effective. ICZM would, however, make it possible to deal with the sectoral regulations that apply to the coastline by having an integrated approach to terrestrial and aquatic elements, and by taking into account the exploitation of resources within environmental protection objectives. Although ICZM aims to apply the principles of sustainable development, it is difficult to achieve because of the profound differences in interests between coastal users, and also because responsibilities are spread across different institutions at different levels, resulting in the dilution of responsibility.

- **Relative protection of land supporting agricultural production**

The law aims to preserve the existence of agricultural land from a quantitative rather than a qualitative perspective, in other words, the availability of land.

In the PLUs, areas of the municipality may be classified as agricultural zones called 'A zones'. These are, whether equipped or not, 'to be protected because of the agronomic, biological or economic potential of the agricultural land'. Land use must therefore correspond to the use of the zone, and authorisation to build or occupy the land must comply with the provisions of the zone regulations that preserve this use. This zoning also has an impact on soil reclamation conditions following the operation of a classified facility. This protection of agricultural land availability also requires the intervention of agricultural and similar bodies when zoning is defined by the commune or intermunicipality: the Chamber of Agriculture is consulted as part of the preparation of the SCOT or the PLU, and the prefect may designate the relevant public department as *Associated Public Persons*.

If the PLU and any amendments (modification/revision/update) result in a reduction of agricultural or forest land, the Chamber of Agriculture, the Regional Centre for Forest Ownership and, where appropriate, the National Institute of Origin and Quality (INAO) must be consulted. It is not, however, simply a consultation. The absence of an enforceable urban planning document does not leave the land without protection, since the rule of limited constructability prohibits construction outside the currently urbanized parts of the municipality, with only a few exceptions such as structures and installations necessary for agricultural exploitation and the development of natural resources. In addition, the authority competent to issue the building permit may refuse the project or accept it only subject to special requirements if its location or destination may compromise agricultural or forestry activities, in particular because 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 this input, along with other consultation, offers only a weak defence against changes in land use. The protection of agricultural land must therefore go through *ad hoc* mechanisms. This is the case for protected agricultural zones (PAZs), which come under the Prefect's jurisdiction; whenever a change in land use or tenure that permanently affects the agronomic, biological or economic potential of an area is planned, the Chamber of Agriculture and the Departmental Committee for Agricultural Orientation are consulted. Should one of these bodies provide an unfavourable opinion of the proposed change, the Prefect must provide reasoned arguments if authorizing this change (C. rural, art L. 112-2). This regime makes it possible to go beyond the short-term economic horizon and to counter local pressure on elected officials. This policy of protected agricultural zones, however, is very rarely applied.

Peri-urban agricultural areas have benefited from special preservation measures since 2005 (Rural Areas Development Act). Departments may define protection perimeters around agricultural and natural peri-urban areas (PEAN) with the agreement of the municipality(s) concerned or the public institutions responsible for PLU matters, after consulting the Chamber of Agriculture and a public inquiry. The advantages of this measure are that the land included in a defined perimeter cannot be included in a zone that is or could be urbanised, nor identified as a buildable zone on municipal maps, and any modification of the perimeter can only occur by formal decree. However, such protection remains fragile, because it depends on the goodwill of the Departmental Government, and it 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 of land pressure.

Local food and agricultural policies raise questions about the use of planning tools. The protection of peri-urban agriculture through municipal planning instruments would be more effective than PLUs, since they would express a local desire to protect agricultural land through joint investment in an agri-urban development project. This approach is a powerful legal instrument for protecting peri-urban farms, provided that it integrates existing agriculture in the territories into its multifunctional dimension.

- **Preserving agricultural land through fiscal tools**

The tax reform measures mentioned above are aimed primarily at addressing the difficulties in access to housing in France, rather than directly improving control over the use of natural and agricultural areas. However, the attainment of the first objective can be helpful in achieving the second.

In favour of a more incentive-based tax system, the release on the market of a greater number of building plots in urban or future urban areas can reduce land pressure in municipalities mainly covered by natural and agricultural areas. However, this positive link is only achievable if the municipalities concerned 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 the 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, especially since its proceeds are used to finance measures to help young farmers set up operations.

This tax is applied on the first transfer of unused agricultural land made constructible after January 13, 2010, by a PLU or a municipal map. Subsequent transfers are therefore not affected by this tax, which ultimately limits its effectiveness.

Box 8-6 - The valuation of agricultural land in the United States

The U.S. government has allowed local governments to apply a use value to land that reflects the income from its current use. Theoretically, taxation of use value makes it possible to delay the conversion of agricultural land, and its effect is particularly significant since 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 the outskirts close to urban areas, where this gap 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 for agricultural maintenance would be insufficient to change behaviour (The Mirrlees Review, 2011). These elements do not argue in favour of abandoning any differentiated tax treatment of agricultural and natural land. They simply point out that the tax incentive has limited effects without a strict zoning or regulatory policy on the part of the authorities.

8.2.3. Densification of already artificialized areas requires a strong will, but leads to relatively positive outcomes.

Since land take often proceeds insidiously, the approach to densification outlined by the 'Urban Solidarity and Renewal' law, and expanded with the ALUR law of 24 March 2014, frees up urban space for densification, provides a stronger legal framework for densification, and thus works in concert with fiscal incentives to densify. However, densification has impacts on biodiversity and human annoyances that must be taken into account by development policies. The threshold effects of urban density highlighted by studies focusing on species and groups 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 designed to limit or offset the negative environmental effects (cf. chapters 2 and 3) of urban densification in the heart of urban areas.

- **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 investments.

- **The freeing-up of urban density and spaces by the ALUR law**

The measurement of urban density had long been carried out using the Land Use Coefficient (COS), a simple and easily-calculated measure, but over-simplifies the issue of density. Indeed, though it allows the definition of a maximum permissible density on a given land parcel by applying a ratio related to the land surface, the COS has limits in its ability to estimate this density. It therefore necessitates looking elsewhere for the required building capacity for a project, especially if the COS is low, as it then restricts the densification of the land concerned. The ALUR law has therefore removed the COS, making densification of land possible (cf. Chapter 5). At the same time, the same law abolished the regime of minimum surface area for building land, in order to strengthen the intramural supply of land and avoid a peripheral extension of the city. However, it has created a new coefficient prone to limiting the artificialization of urbanised spaces (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 institutions for intermunicipal cooperation (EPCI) to combat urban sprawl. To this end, the municipalities and EPCI responsible for urban planning may institute a minimum density threshold below which a payment for under-density is due (C. urb., art. L. 331-36) and they will benefit from the proceeds of these payments. A PLU is necessary since this threshold is determined by zones within the municipality that are urban or are to be urbanized. 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.

• Strengthening land use regulations: quantifiable targets

Directed by the 'Grenelle 2' law to combat space consumption, SCOTs and PLUs must include, in their presentation reports, an analysis of the consumption of natural, agricultural and forest areas.

The ALUR law reinforces these provisions and the SCOT presentation report must now 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 evolution of which must be analysed. With this in mind, the PLU's development 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 guidance document and objectives, with reference to the analysis of past space consumption.

8.3. Mechanisms to reduce the effects of land take

When land take cannot be avoided, for example to satisfy housing needs, or because the legal mechanisms at work have not led to the project being challenged, levers exist to reduce the impacts of land take on the soil itself and on the environment more generally.

The first of these levers lies in the knowledge of the soils and environment over which the transformation is projected (8.3.1). It is then supplemented by measures to recycle artificial land (8.3.2) and to limit the waterproofing of artificial surfaces (8.3.3).

8.3.1. Knowledge of soils and the environment before land take: a challenge for public policies

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

Land use is not the main concern of the environmental impact assessment regimes for some public or private projects (Directive 2011/92/EU), nor of the environmental impacts of some 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 factors likely to be significantly affected by the project, including land and soil, as well as 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 present, the approach is essentially surface-based. In-depth case-law analyses have found that no decision or plan has been annulled on the grounds that the impacts of a project on soil quality have not been sufficiently taken into account.

In addition, the scope of environmental assessment mechanisms does not cover a significant number of operations that ultimately result in land take, such as solar power generation facilities below 250 Kwp, or 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 the impacts of a plan, programme or project on 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 on a human scale. There is no doubt that a better consideration of soil quality would considerably reduce the impacts of land take on the environment (see below). This collective scientific report, importantly, reveals a lack of knowledge on the baseline state of the environment and in particular of the soils, which prevents any real measurement of the impact of land take. The obligation to measure and preserve this state could be created by 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, in some instances, the environmental assessment must include remediation measures, thus allowing the condition of the environment to be forecast over time. In terms of land take, the introduction of such a document would make it possible to provide for measures limiting land take, at the project design stage. This important instrument addresses the issues of reversibility and the objective of no net loss of biodiversity.

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

Soil quality is rarely used as the factor cancelling the decision to classify land as buildable, unless there was an obvious error of assessment. This situation highlights the fact that the classification is more often the result of a desired assignment than the quality of the soil.

To reverse the trend in the long term would probably involve following the Uqualisol-ZU project (Soil use and soil quality in urban and peri-urban areas - application to the Provence Mining Basin) and its recommendations, formulated under the 'Gessol 3' programme. It would require the creation of soil quality indices and their integration into urban planning documents. These indices would allow correlation with the possible uses of the soil in order to allocate it as accurately as possible to different land uses according to their qualities. Thus high-quality soils would not be 'wasted' by land take (in terms of these 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.

This classification of soils via composite indices is attracting growing interest. But there is no consensus concerning, firstly, the measurement of soil quality and, secondly, which parameters are most relevant or essential when describing the characteristics and potential of these soils. However, contamination regulations (exposure and health risk assessments for the population) appear to play a leading role in the characterization of these soils.

8.3.2. Land recycling

One major challenge to reducing the impacts of land take lies in preventing the conversion of agricultural or natural parcels to a non-reversible artificial state (waterproofing). In this context, land recycling is a key priority, but its implementation reveals potential public health issues. The conversion of former industrial sites into housing or establishments for the public is a challenge for the public authorities who must supervise the rehabilitation of polluted sites and soils. Some residual pollution can become a source of nuisance over the long term. In this case, soil conservation can conflict with the preservation of human health, necessitating both public and private law to arbitrating on these types of redevelopments.

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 vacant spaces. Forethought is a key factor here and allows the identification of sites that are likely to form the basis of new multifunctional networks of transit and green spaces. The assemblage of vacant, interstitial spaces ('hollow teeth') requires policies that provide incentives for owners to cooperate, by providing stronger densification capabilities in targeted areas. If necessary, these policies would be complemented by actions carried out by public land authorities through the exercise of their right of purchase.

Also, the literature exposes a need to renew the means and tools for funding projects. In addition, with regard to control procedures, it may be possible to establish a reference standard for the quality of urbanized soils 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.

8.3.3. Limiting the sealing of artificialized areas

The sealing of surfaces makes it very 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.

- **Protecting 'Nature in the City'**

In line with these goals are interesting mechanisms, such as the identification of ecological corridors through urban planning documents, and the biotope coefficient. Created by the ALUR law, the biotope coefficient applies at the municipal or inter-municipal level; the PLU can set rules imposing 'a minimum allocation of permeable or eco-sustainable surfaces, possibly weighted according to their characteristics, in order to contribute to the maintenance of biodiversity and nature in the city'. Based on a ratio of the area favourable to nature to the area of a constructed parcel, this coefficient makes it possible to determine the portion of the area of a site that is vegetated or performs other ecosystem functions. Berlin's application of the biotope coefficient is the most extensive to date. They found it to 'contribute to the standardization and realization of the following environmental quality goals: to ensure and improve microclimate and air quality; to develop and maintain soil function and manage water resources; to create and enhance living space for fauna and flora; and to improve the living environment'. A coefficient is thus applied to each surface type (for example: waterproofed 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 is also useful in tempering the adverse effects of urban heat islands. It is recognized that grassy or bare soils, as well as the presence of trees, can contribute to this, although further knowledge is needed.

Furthermore, the impacts of structures on biodiversity could be better understood, and their integration would require only minor changes to the existing legal framework. For example, in terms of urban development, the building code could pay greater attention to biodiversity by encouraging the heterogeneity of building heights and vegetation strata that favour bird abundance in a dense city.

- **Water management and limiting the sealing of surfaces**

Soil restoration appears to be on the agenda, 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 the subject of measures to limit ground sealing, with the objectives of flood regulation or reducing runoff and associated pollutants. Thus, the Water Act of 3 January 1992 instituted Article L. 2224-10 of the General Local Authorities Code, requires mayors to delineate areas for municipal and non-municipal sanitation, along with 'areas where measures must be taken to limit soil sealing and to 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'.

The measures undertaken include the construction of permeable surfaces, i.e. gravel, grass or interlocking paving stones, etc., which must be accompanied by work to increase the soil's absorption capacity (to achieve a result of about 1 cm/s).

Box 8-7 - The rainwater management levy: a tool to limit soil sealing

The Grenelle II law allows municipalities that collect rainwater to introduce an annual rainwater management tax. This optional mechanism should be noted because of the rebates it provides.

These rebates are intended to compensate for the installation of devices limiting the discharge of rainwater off a site. These devices do not depend solely on the amount of sealing on the parcel. They mainly consist of the installation of gutters and drainage systems.

However, this tax is based on the surface area of the parcel, with the law stating that any permeable areas on the parcel will be subtracted from the total surface area when calculating this tax. Therefore, the law recognizes the role of soils in the absorption of rainwater and their contribution to reducing the risk of flooding. This tax could therefore encourage landowners to limit the surface sealing of their parcels.

8.4. Mechanisms to compensate for the effects of land take

Currently in France, there are no specific compensation mechanisms to offset artificialized land and/or its most important impacts (on biodiversity, hydrology, soil pollution, urban climate). However, there are three mechanisms that could be applied: 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 texts previously considered touch upon compensation for environmental damage in general, and to soil in particular. Compensation is a 'broom 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 if ever addressed in urban planning law, whereas it is more common 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 execution of a works or structure project or by the execution of 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 corrective measure was therefore taken requiring the project owner to monitor the implementation of these measures and their effects on the environment. The Environmental Code provides for regular reports to be submitted to the relevant authority, which may order corrective measures and generally guarantee the proper execution of these measures (formal notice and automatic action in the event of default, criminal penalties, and financial guarantees). Therefore, in the case of land take, the measure could consist, for example, of rehabilitating an artificialized area by restoring its natural functions, or the preservation of environments that compensate for ecosystem services affected by such land take.

• Forest compensation: the development of an economic compensation mechanism

The Forest Code, for example, 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, determined according to 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 of the Future for Agriculture, Food and Forestry (2014) requires the completion of a preliminary study for the project owner of a public or private development or action likely to have significant negative consequences on the agricultural economy. This study is part of the 'agricultural collective compensation'.

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

1. 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 conditions.
2. These projects must also have right-of-way over parcels affected or having been assigned to an agricultural activity in accordance with Article L. 311-1 of the Rural and Maritime Fisheries Code, in either the last 5 or 3 years (depending on their location in urban planning documents).
3. Projects must involve the definitive removal of an area, in principle larger than 5 hectares.

This instrument is still too new to fully assess the effects of its implementation. Furthermore, it is important to note that compensatory measures are not necessarily expressed in terms of land.

• Compensation for land take: future prospects?

Germany is regularly cited as an example of a country having implemented a compensation mechanism for land take. In fact, since the end of the 1990s urbanization has been offset using an 'ecopoint' market (tradeable environmental credits) run by agencies at the state (Länder) level. In addition, the example of the city of Dresden should be mentioned. Measures for 'soil unsealing' compensation have been explicitly provided for, and between 2000 and 2008, an average of 4 ha per year was 'unsealed'.

A development charge is also under consideration. Examples include the Czech Republic and Slovakia, which have both created a classification of agricultural land according to their fertility. When a project involves the conversion of high-quality land, the developer must apply for a special permit issued either by the Region or the Ministry of the Environment and pay a sum corresponding to the price per square meter multiplied by the artificialized surface. However, this mechanism is considered very lenient given the fees, especially in zones of strong land pressure.

A current French example is the transfer of building rights (Chapter 5). 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 in part to the lack of a sufficient market to set consistent prices, legislative constraints, and the prior approval regime in place. It could perhaps be developed under the impetus of the ALUR law (2014) which created a mechanism for the transfer of constructability in areas to be protected on the basis their landscapes.

8.5. Conclusions

Avoiding, reducing or compensating 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 the study of French law:

- There are legal controversies over the notion of land take, which is not defined by law and is a concept that is not found in European or international texts.
- As a result, there is no general policy to combat land take. The public authorities, at the national level, have a limited approach by concentrating, for example, on the fight against the subdivision of agricultural land. The effectiveness of the existing tools is then reduced, especially since their implementation is rarely binding.
- More generally, 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 the text or the judicial decision concerns it (such as the specific provisions of the ALUR law). Land take, under this denomination or under terms that evoke it (urban sprawl etc.), is more often addressed incidentally, in the course of a provision.

A definition of land take, or criteria to characterise it, would make it easier to legally understand, 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 allow soil to be made a 'national cause' (the protection of soil against land take is an objective of general interest). It would also raise awareness of soil protection and, importantly, provide the basis for the adoption of legal provisions capable of satisfying this goal.

Taxation is not neutral for 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 often range beyond the boundaries of municipalities, the growing importance of intermunicipal cooperation on this subject should be encouraged.

Despite the political impetus for ecological transition (2013), little work has been undertaken with regard to financial and fiscal instruments that encourage densification, not so much because of the technical nature of the exercise but because of the lack of specialists on these subjects. The bulk of the issue was addressed in the framework of the French Committee for Ecological Taxation (now the Committee for the Green Economy). Other suggestions that should be explored were made by this Committee, such as taxation of vacant offices along the same lines as taxation of vacant dwellings, which would encourage them to be put on the market rather than building new ones, and taxation of industrial and commercial wasteland 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 taxation linked to land is possible to limit urban sprawl and land artificialization, 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' zones;
- The income from taxation introduced to limit the use of land must not benefit the authority establishing it, its purpose being deterrence and not the generation of profits;
- 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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