



URBAN SMS Soil Management Strategy



Climatic Impacts of Urban Soil Consumption

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Climatic Impacts of Urban Soil Consumption

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Review and System Model

Executive Summary

A contribution to WP6 „acceptance and awareness“
in the EU Project URBAN-SMS



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URBAN SMS
Soil Management Strategy

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1 Introduction

In recent years a broad public has become aware of the observed as well as predicted climatic changes. The consequences of this development are viewed as one of the main challenges humanity will be facing in the 21st century. Presently few scientific disciplines and stakeholders can elude the debate on the anthropogenic greenhouse effect and global change. The global atmospheric concentration of carbon dioxide, methane and nitrous oxide has increased since the beginning of industrialisation as a result of human activities, and exceeds the values that have been obtained from various geological archives (e. g. ice cores). Changes in the atmospheric concentration of these gases and aerosols together with changes of the land surface structure slowly modify the global radiation balance, which is considered to be the main driving force behind climate change (IPCC 2007).

In addition, urban structures cause some instantaneous and local modifications of the urban atmosphere which constitute the urban climate. High summertime temperatures and particulate matter (e.g. PM₁₀) exposure in the ambient air cause certain negative health effects, which should be minimized.

The functional soil-vegetation system plays a decisive role on both, the global as well as the urban climate scales, by exchanging greenhouse gases, energy and particulates with the atmosphere. Within the framework of the EU-funded project, URBAN-SMS, a system model was developed, which contains all climate-relevant mass and energy fluxes caused by urban soil consumption (fig. 1). It is based on an extensive literature review. Furthermore, a quantification of the greenhouse gas emissions was carried out, propelled by the urbanization and land utilization within the city boundaries of Stuttgart. In addition, the scenario “What happens, if one hectare of rank soil is sealed during the process of urban soil consumption?” was quantified for each topic in order to help raise acceptance and awareness for the soil protection issues.

Since soil protection comes along with restrictions and limitations in the scope of action of various stakeholders, it is necessary to raise the awareness for the harmful impacts of encroachments on the soil resource as well as the acceptance of soil protection measures. This can be achieved by basic explanatory work. The outcome of this study will provide an understanding of the scientific knowledge of the climate-relevant processes and enable an exemplification.

2 Global climate impacts

The radiation budget of the climate system is substantially driven by atmospheric greenhouse gas concentrations. The increased concentrations caused by human activities lead to an adap-

Climatic impacts of urban soil consumption

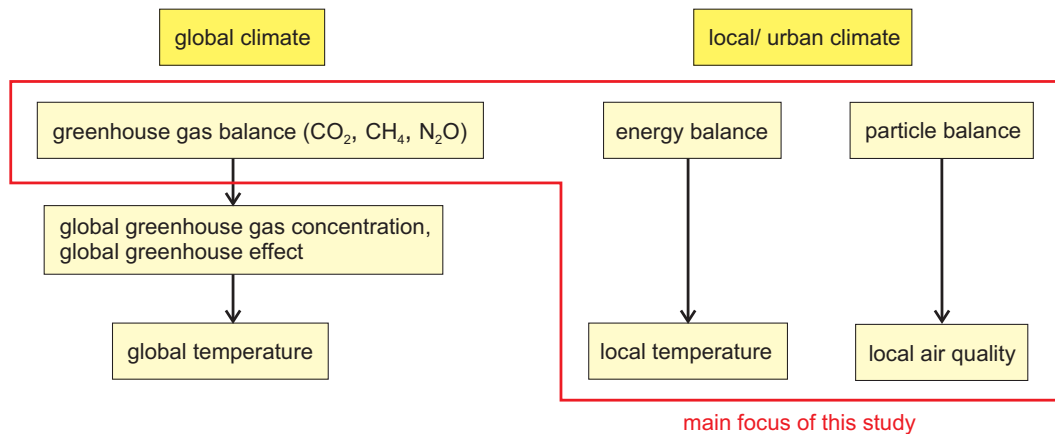


Fig. 1: Main focus of this study. On the scale of global climate, the dynamic of the greenhouse gases carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) was reviewed. On the scale of urban climate, the surface energy and particle balance and their impact on local air temperature and air quality were studied.

tion of the earth's radiation budget and atmospheric warming, which is called the anthropogenic greenhouse gas effect. With respect to their warming potential, these gases differ in their radiation properties and their mean atmospheric lifetime. Based on these properties and a given time horizon of 100 years, CH₄ is a 25 times more effective greenhouse gas and N₂O a 298 times more effective greenhouse gas than CO₂ (IPCC 2007).

2.1 Carbon dioxide (CO₂)

CO₂ and CH₄ play a decisive role in the natural carbon cycle, where massive carbon fluxes occur between the oceanic pool, the terrestrial biosphere, and the atmosphere. In comparison to the natural fluxes, the anthropogenic fluxes are rather low. Nevertheless they have led to measurable changes of the global C-distribution since preindustrial times (LAL 2008, IPCC 2007).

Through the process of photosynthesis, CO₂ is removed from the atmosphere by plants and converted into biomass. When the dead biomass is translocated into the soil, it contributes to the formation of soil organic carbon (KUZYAKOV & DOMANSKI 2000). The carbon stored in plants and soil loses its global warming potential. Through plant and soil respiration (respiration and decomposition processes) this organic carbon is released again into the atmosphere as CO₂ during aerobic respiration or, as for CH₄, during anaerobic respiration. The carbon balance of the soil is therefore dominated by two opposing processes, the C-input into the soil due to the photosynthesis and the C-output which is due to the decomposition processes. Both flows show a dynamic equilibrium, which is dependant on site properties and land use. The soil reacts towards changes pertaining to the control variables by increasing or depleting its soil organic

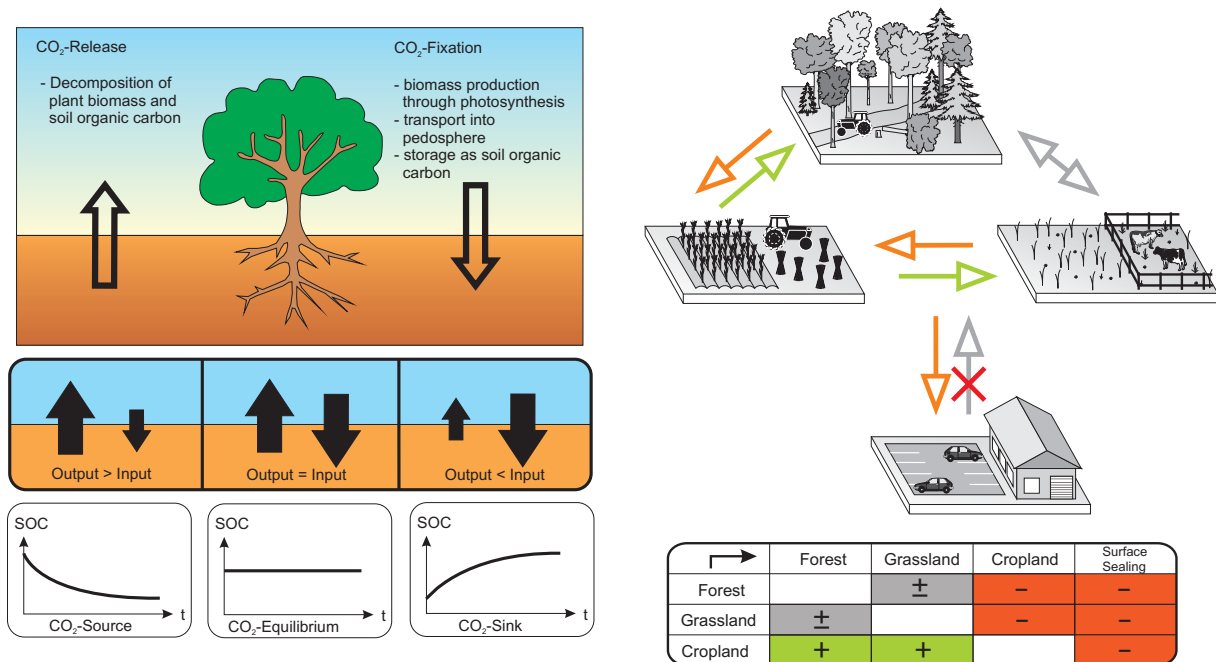


Fig. 2 (left): The amount of soil organic carbon (SOC), which is contained in soils, represents a dynamic equilibrium between carbon uptake and carbon release. Various environmental factors, but also anthropogenic activities can lead to a disruption of this equilibrium. An imbalance of opposing flows results in a temporal change of organic carbon content and thus a net flux of CO₂ between atmosphere and soil.

Fig. 3 (right): Matrix for the changes of soil organic carbon following land-use conversions. Green arrows (+) mean an increase in carbon stocks and red arrows (-) a depletion and a release of carbon. The conversion of grassland to forest and vice versa show no clear and significant trends (±). In the professional practice the recultivation of sealed soil is limited to small areas because of the high costs (GERST, 2010, extended).

carbon content until a new equilibrium between inputs and outputs is reached. If a change leads to an increase in soil organic carbon content, the soil will act as a CO₂-sink. Conversely, during soil organic carbon reduction the soil acts as a CO₂-source (fig. 2). The time for reaching a new equilibrium is site and land-use specific, and can last between 20 and 100 years (FREIBAUER et al. 2004, SMITH 2004, WEST & SIX 2007).

The conversion of forest and grassland into cropland generally leads to a loss of soil organic carbon and thus to CO₂ emissions until a new equilibrium is reached (fig. 2 and fig. 3). The conversion of cropland to forest and grassland is associated with the accumulation of soil organic matter. The conversion of grassland into forest and vice versa, however, shows no clear and significant trend in the soils (POST & KWON 2000, GUO & GIFFORD 2002, MURTY et al. 2002, POEPLAU et al. 2011).

Even within the land-use categories, forests, grassland as well as cropland all create opportunities that influence the CO₂ balance. Carbon sequestration implies transferring atmospheric carbon into the biotic and pedological pool so that it is not immediately reemitted. This is associated with an increase in the biomass pool and an increase in the equilibrium of soil carbon

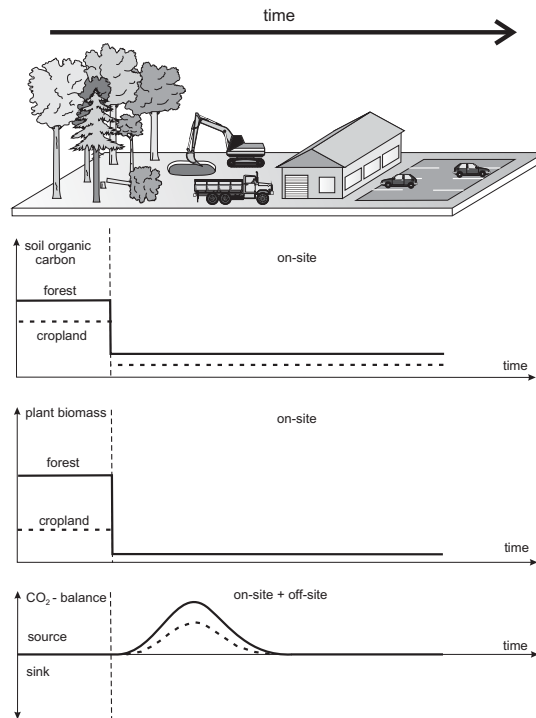


Fig. 4: Schematic profile of the carbon dynamics following urban soil consumption. On-site these encroachments lead to a loss of biomass stocks and to a depletion of soil organic carbon. It is professional practice to excavate the topsoil prior to building activities and reapply it at other locations. In addition, the plant biomass is removed by lateral transport and, after a delay is also ultimately oxidized. It is therefore necessary to consider the fate of organic carbon on-site and off-site. Thus surface sealing can be expected to trigger short-term CO₂ emission pulses (GERST 2010).

levels (LAL 2004a, LAL 2008). This is achieved in agricultural and forest soils by an extension of management, an increased return in plant residues, a reduction of the mechanical disturbance of the soil structure (e. g. through reduced tillage) and the optimization of fertilization as well as other improvements in productivity (FREIBAUER et al. 2004, LAL 2004b, LAL 2005, SMITH et al. 2008).

Although the carbon dynamics in the land use categories forest, grassland and cropland are well documented, little is known about the fate of the soil carbon stock after urban soil consumption. The humic topsoil is protected by law and it is common professional practice that prior to building activities it will be excavated, stored, transported and applied at another location. The fate of this carbon pool has not been reported in literature so far (POUYAT et al. 2010). The transported humic soil material undergoes a severe disruption in its structure (POUYAT et al. 2007) and after its application at a different location, it becomes part of a local equilibrium dynamic again. Therefore, it is assumed that at least part of this organic matter decomposes and is recycled into the atmosphere in the form of CO₂ emissions. This assumption is also supported by the Guidelines for National Greenhouse Gas Inventories Reporting of the Intergovernmental Panel on Climate Change (IPCC 2006). Here the assumption is, that during the surface sealing

process 20% of soil organic carbon in the topsoil (upper 30 cm) is lost and released into the atmosphere by disturbance, removal or relocation. Thus it can be assumed that the sealing of soils results in a singular CO₂-emission pulse (fig. 4). For these mechanisms, however, basic research is needed and the quantification is accompanied by large uncertainties.

Presuming that unsealing and land reclamation is technically and economically not feasible and considering that regeneration takes a very long time, this process is irreversible. Sealed soils are thus lost as a carbon storage medium and as a habitat for vegetation, which occupy a key functional role in the carbon cycle. Future carbon storage by sequestration activities is no longer possible. If the overbuilt ecosystems functioned in the form of a CO₂-sink (e. g. forest soils and peat soils) the positive benefit is omitted.

2.2 Methane (CH₄)

Methane is produced in anoxic environments during the anaerobic decomposition of organic matter. Such conditions occur if oxygen exchange is hampered by water saturation, e. g. in hydromorphic soils. Upland soils are not under the influence of the groundwater body and are generally regarded as methane sinks. There CH₄ diffuses into the soil matrix and is oxidized with the participation of various microbial populations (LE MER & ROGER 2001).

Land-use changes, as for example the reclamation of natural ecosystems, strongly reduce the soil's sink strength for atmospheric methane. The annual oxidation rates of agro-ecosystems compared to forest ecosystems are greatly diminished. The overall sink strength of soil decreases in the order forest > grassland > cropland (SMITH et al. 2000, BOECKX & VAN CLEEMPUT 2001, DUTTAUR & VERCHOT 2007). The oxidation capacity of soils in urban parks and woodland do not remain unaffected. With respect to the few studies conducted here, a drastic reduction of methane consumption all the way to a total loss of sink strength could already be observed (GOLDMAN et al. 1995, KAYE et al. 2004, GROFFMAN & POUYAT 2009). By sealing the surface the methane sink is completely lost. This quantitative impact upon the full greenhouse gas balance is, compared to the greenhouse gas fluxes of CO₂ and N₂O, however, minor.

2.3 Nitrous oxide (N₂O)

The third major long-lived greenhouse gas, nitrous oxide (N₂O), is continuously released from soils. Here N₂O is produced mainly as an intermediate or by-product during the biological processes of nitrification and denitrification in the nitrogen cycle. Emissions occur directly from the soil, e. g. as a result of anthropogenic nitrogen addition to croplands and grasslands. Indirect

emissions emerge from the increase in atmospheric N-deposition into ecosystems (following volatilization of NH_3 and NO_x from managed soils, fossil fuel combustion, biomass burning as well as the subsequent redeposition of these gases) and after leaching and the runoff of nitrogenous compounds (mainly NO_3^-) from managed soils into aquatic systems (IPCC 2006, FIRESTONE & DAVIDSON 1989, WRAGE et al. 2001, BREMNER 1997, WEYMANN et al. 2008, WELL & BUTTERBACH-BAHL 2010).

The production rates of N_2O in the soil are controlled by a number of different variables at different temporal and spatial scales (FREIBAUER & KALTSCHMITT 2003, MACHEFERT et al. 2002, DOBBIE & SMITH 2003, JUNGKUNST et al. 2006). The calculation and prediction of anthropogenic emissions is generally based on the N-availability. In most soils an increase in nitrogen availability enhances nitrification and denitrification rates, which in turn increase the N_2O production. An increase in N-availability can on the one hand be due to addition of nitrogen compounds (e. g. in the form of fertilizers) or on the other hand as a result of humus-depleting land use practices (SMITH & CONEN 2004, IPCC 2006). Agricultural soils are assumed to be a hotspot for N_2O emissions and are made responsible for much of the observed increases in atmospheric concentrations (DAVIDSON 2009, SMITH et al. 2010). When land-use changes lead to a depletion in soil organic carbon contents (e. g. urban soil consumption), apart from CO_2 , N_2O is also emitted into the atmosphere. This occurs directly from soil and indirectly from adjacent waters. Furthermore the sealing of soils leads to a long-term prevention of the continuous release of N_2O . The relocation of agricultural production however, increases emissions elsewhere.

2.4 Greenhouse gas emissions through urbanization in Stuttgart

The calculation of greenhouse gas emissions (CO_2 and N_2O), which were triggered by the urbanization in the district of Stuttgart, is based on the IPCC Guidelines for National Greenhouse Gas Reporting (IPCC 2006). For this, a number of simplifying assumptions had to be made. More detailed explanations are listed in the long version of the project report. Due to losses in soil organic carbon and vegetative biomass triggered by soil consumption between 1980 and 2009, roughly 64 468 t CO_2 -equivalents were emitted (in the form of CO_2 and N_2O). An average for the observation period, results in an annual rate of 2 223 t CO_2 -eq. a^{-1} .

As published by the Statistical Office of Stuttgart, CO_2 emissions (energy, industry, small consumers, transport) in the city of Stuttgart in 2005 amounted to 3.4 million tonnes of CO_2 a^{-1} . Thus, the rate of emission of greenhouse gas brought about by the development of residential, industrial and traffic areas corresponds to about 0.06% of the rate of CO_2 emission through technical use. Even the assumption that the organic carbon in the upper 30 cm of the sealed

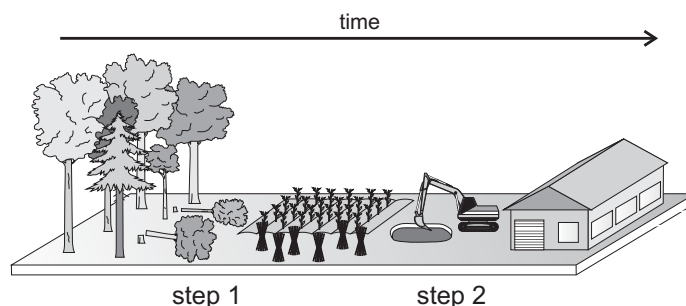


Fig. 5: Chronological land-use sequence for a primary forest ecosystem to an agricultural ecosystem all the way to an urban land-use. With the associated land use changes, large amounts of previously stored carbon were continuously released into the atmosphere.

soils is completely decomposed (five-fold enhancement of the soil-borne CO₂ emissions), only increases the value to roughly 0.3%. The calculations of CO₂ emissions from the terrestrial carbon pool reflect, at best, the magnitude of actual flows because of assumptions, simplifications and uncertainties. Nevertheless, it is clear that the negative effects of soil utilization are subordinate to CO₂ emissions from the energy and transport sectors.

Looking at the impact of land use changes on a longer time scale, emissions add up to a level that certainly has some relevance with regard to the climate system. Through chronological sequences in the entire history of settlement, such as clearing, land reclamation and building activities on previously natural ecosystems, carbon and nitrogen was constantly released into the atmosphere (fig. 5). Associated greenhouse gas emissions for the district of Stuttgart amount to about 10 million tonnes of CO₂ equivalents (for detailed explanation see long version of the report). Here, changes in the biomass stocks of the cleared forests are of particular importance.

In order to assess the climatic impacts of urban soil consumption, indirect impacts may not be overlooked. The loss of agricultural land means that for compensation and maintenance of agricultural production the management of the remaining areas must be intensified or new land must be reclaimed for cultivation. This applies particularly to the rising food and bio-energy demands of a growing world population. Thus, land utilization in Europe can also cause indirect emissions, e. g. through the cultivation of primary forests on other continents. Additional emissions occur with the transportation of agricultural goods to Central Europe.

3 Urban climate impacts

The previous section showed that large-scale land-use changes lead to a change in atmospheric greenhouse gas concentrations and the anthropogenic greenhouse effect. Besides these slow global climate processes, man is constantly being exposed to local and instantaneous environmental influences. In comparison to their surrounding area, urban structures generate some

climatic effects on air temperature and air quality, which is known as urban climate. According to BARLAG & KUTTLER (2002), the causes of the urban climate can be traced back to three basic groups of factors:

- conversion of natural soil into sealed areas consisting of artificial materials with strong three-dimensional structure,
- reduction of areas covered with vegetation,
- release of gaseous, liquid and solid impurities as well as waste heat from technical processes.

The urban atmosphere is part of the environment, the human body needs to adapt to maintain good health. High temperatures during the summer months and high particulate matter loadings in the ambient air lead to negative health impacts that need to be minimized by way of urban development and planning measures.

3.1 The importance of soils for urban air temperatures

One of the best documented and studied urban climate aspects is the urban heat island, which is characterized, compared to the surrounding area, by higher surface and air temperatures (MATZARAKIS 2001). The causes for temperature enhancement of urban areas are manifold, a major part however results from soil consumption and surface sealing (KUTTLER 2004).

Differences in surface reflectivity, thermal conductivity, heat capacity, and water retention capabilities lead to characteristic temporal surface and air temperature courses in surface materials. By changing the thermo-physical properties of these surfaces and their characteristic evaporation traits, the heat balance is modified in such a way that sealed areas, compared to plant covered soils, favour temperature enhancements. In comparison to sealed surfaces, plant covered soils warm up more slowly during the day due to higher evaporation, and cool down faster during the night due to lower heat storage. Through the process of evaporational cooling, part of the incoming radiation is not transferred to sensible heat in the surfaces and the adjacent air masses, which counteracts urban overheating. The available water capacity of soils (water holding capability against gravity) enables the moisture supply to plants as well as to soil surfaces and extends, in comparison to sealed surfaces, the actual rates of evaporation to be maintained after precipitation events (KUTTLER 2004, ASAEDA et al. 1996, HUPFER & KUTTLER 2005, WESSOLEK 2001).

Surface and air temperature studies clearly show that these parameters correlate with the degree of surface sealing and vegetation coverage (BAUMGARTNER et al. 1985, KUTTLER et al.

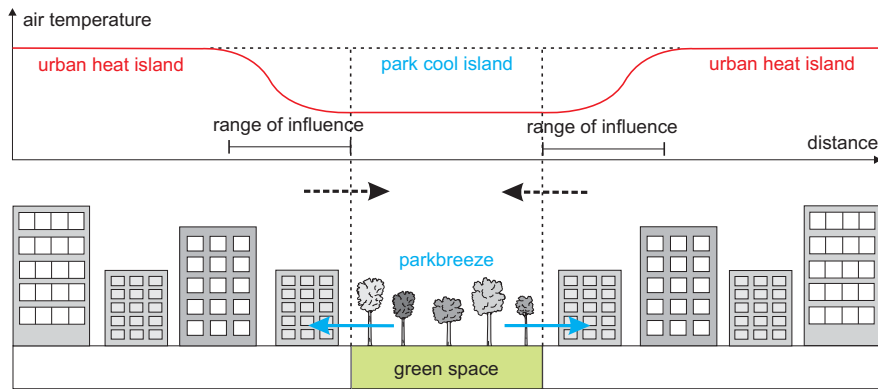


Fig. 6: Schematic diagram of the thermally-induced circulation within urban green areas with at low wind intensities (ELIASSON & UPMANIS 2000, modified).

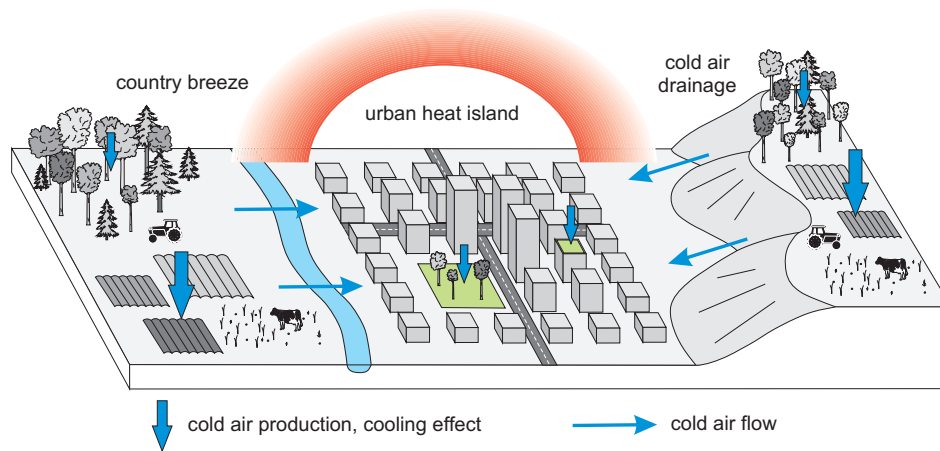


Fig. 7: Schematic diagram of the transport paths of cold and fresh air from the surrounding countryside into the settlement area. A differentiation between country breezes in plain topographies and cold air drainage in complex topographies (katabatic wind systems: downslope winds, mountain winds) can be made. In addition to the extra-urban cold air production areas inner-city green spaces and green roofs are of importance for the thermal urban climate, due to their cooling effect.

1996, KIESE 1992, CHRISTEN & VOGT 2004, WENG et al. 2004, YUAN & BAUER 2007). This is also visible in airborne thermal remote sensing images.

The cities of Central Europe usually have areas of green and open space which have meliorative effects on the thermal climate of the city. In analogy to the urban heat island, a microclimatic temperature reduction of intra-urban green areas and parks is called park cool island. Many studies have already observed that the cool island extends across the edges of the parks into the adjacent street canyons (BONGARDT 2006). Through a small-scale thermally induced air circulation colder air is transported radially from the green areas, which can thus have a positive effect away from the green spaces (fig. 6). This air flow is referred to as a park breeze (OKE 1989, KUTTLER 2010).

The urban climate is generally characterized by a limited exchange of air, which is caused by increased roughness parameters as well as inversions in the urban atmosphere. Through air flows at near-ground level, local cold and fresh air can, regardless of large-scale wind condi-

Table 1: Urban climate functions of green and open spaces and the consequences of soil consumption.

	cold air production area	ventilation path	settlement area
function	cold air production fresh air production	ventilation/ air exchange (cold air production) (fresh air production)	green space: reduction of urban heat island, filtration and sorption of airborne particulates
soil consumption	impairment of the function	impairment of the function	Enhancement of urban heat island, loss of filtration and sorption potential

tions, reach from the surrounding countryside into the settlements and can there lower temperatures as well as improve air quality. This transportation takes place in a plain topography in the form of country breezes (SCHADLER & LOHMEYER 1996, KUTTLER et al. 1996, KUTTLER et al. 1998, JUNK et al. 2003, WEBER & KUTTLER 2004, MATZARAKIS et al. 2008) or in a complex topography in the form of cold air drainage (BARLAG & KUTTLER 1990, KIESE et al. 1992, KUTTLER et al. 1998, HAEGER-EUGENSSON & HOLMER 1999, HIDALGO et al. 2008; fig. 7). The cold air drainage area includes those areas of cold air production that are of importance for a particular location. There the cold air productivity is determined by the surfaces` local site properties. Through ventilation paths the cold air which was formed reaches into the settlement area. In order to ensure these ventilation processes, the ventilation paths have to meet specific structural requirements. A dense and high development, as well as natural dams means that ventilation cannot flow around these obstacles. In the worst case, the flow impeding influence leads to a stagnation of cold air flow (VDI 2003, HORBERT 2000, WEBER & KUTTLER 2003).

Thus, besides the inner-city green spaces, the green as well as the open spaces close to the city are also of great importance for urban climate processes. The soil consumption in areas of cold air production reduces the productivity of cold air, similarly the structural reshaping of ventilation paths decreases the cities` aeration (tab. 1).

3.2 The importance of soils for urban particulate matter exposure

The problem of high particulate matter (e. g. PM_{2,5} and PM₁₀) loads of the ambient air, generally in urban areas, is an important issue since different sources of emission are concentrated in a confined space. Legal regulations require the production of specific air quality, regardless of the contributions by different sources with regard to the total emissions. First of all, the strength of the sources can be reduced and secondly the strength of the sinks can be increased in order to achieve these goals. For the latter, the role of inner-city vegetation as a filter and soils as sorbent for particles has been widely discussed recently.

Table 2: Positive and negative effects of urban vegetation on the dust concentration in the urban atmosphere (LANGNER 2008, modified).

Decrease in particle concentration	Increase in particle concentration
direct: filtering by deposition indirect: modification of airflow reduced resuspension	direct: emission of particles indirekt: modification of airflow

In addition to the emission and formation processes, the removal through deposition processes is also of importance with regard to the atmospheric particles budget. During the process of dry deposition, particles are transported and bound to surfaces (soil, vegetation, roads, and buildings) by various mechanisms without the participation of water. The wet deposition takes place in conjunction with precipitation, however, plants have little influence on these processes (HAINSCH 2004, MÖLLER 2003, LITSCHKE & KUTTLER 2008, IASP 2007).

The filtering potential of urban vegetation stocks can be attributed to the increase in surface area for deposition in relation to the base area. In the course of this, tree stands with large surfaces are more efficient dust collectors than low-growing vegetation (MCDONALD et al. 2007, FOWLER et al. 2004, BECKETT et al. 2000). The assessment of the filter performance of urban vegetation and its effect on atmospheric particle concentrations is controversial in literature (LANGNER 2006, NOWAK et al. 2006, MCDONALD et al. 2007, FREER-SMITH et al. 2005, IASP 2007, LITSCHKE & KUTTLER 2008). While there is consensus among experts that plants can filter particles from the air, the quantitative effect on urban air concentrations is judged differently. The advantages of large contiguous green areas are frequently pointed out in this context. It should be noted that the filtering capacity of vegetation has probably been overestimated in the past.

The effects of vegetation are not limited to the deposition of airborne particles on vegetation surfaces (tab. 2). By changing the air flow, positive and negative effects may result locally through:

- changes in wind speeds,
- diversion of polluted air currents and generation of turbulence (fig. 8)
- reduction of ventilation in urban canyons or larger areas (fig. 9).

With the diversion and lifting of air flows by green elements, areas at ground level can be created which are less dust-polluted (fig. 9). SWAAGSTRA & KLUIVER (2006) rely on studies in which the local particle concentration in the air was reduced by up to 20% through linear green elements.

As the particle concentration in the air is greatest in the vicinity of the particle sources, there the filtration performance of the vegetation is highest. Vegetation structures, however,

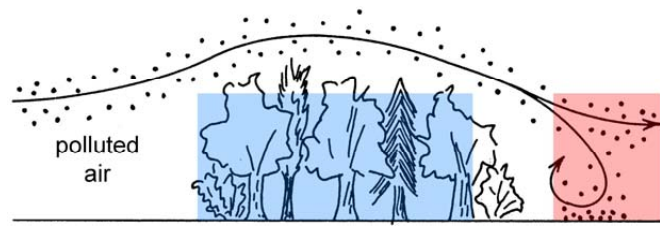


Fig. 8: Changes in the wind field can distract polluted air and locally cause a reduction (blue) and an increase (red) in particle concentration (LANGNER 2008 modified from FELLEBERG 1999).

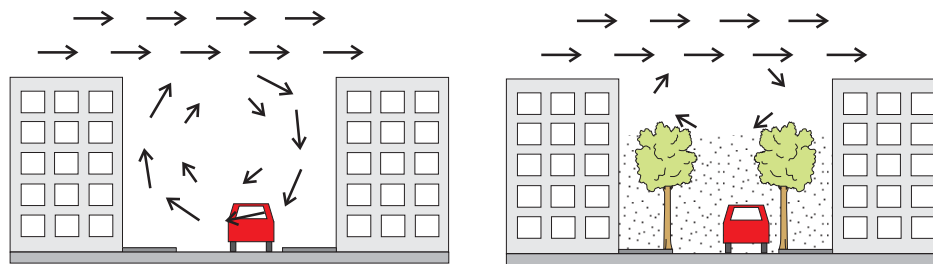


Fig. 9: Effect of roadside trees in a street canyon. The ventilation and thus the air exchange may be impaired by the green elements. As a result, particle loads increase in the vicinity of the sources. However, a distinction must be made between windward and leeward facade (THÖNNESSEN 2006, modified).

often reduce the air exchange of the near-ground boundary layer and thus prevent a dilution of concentrations. Locally, near the sources, this can lead to a deterioration of air quality (fig. 9). Especially in narrow settlement structures (such as street canyons) the unimpeded removal of polluted air is of great importance for air quality. The increase in concentration by green elements counteracts the effect of dust filtering (LITSCHKE & KUTTLER 2008, RIES & EICHHORN 2001, GROMKE & RUCK 2007, BRUSE 2003). In order to optimize the effect, it is necessary to provide large plant surface area without interfering with the air exchange.

The plant surfaces, which are coated with particles, store these only temporarily. Part of the deposited particles is resuspended directly from plants (OULD-DADA & BAGHINI 2001). Another part is washed into the underlying soils by precipitation, deposited on impervious surfaces or washed into the canalization. The particles, that adhere with the foliage more strongly, reach the soil surface through litter-fall. This percentage is then possibly collected and removed along with any of the green waste adhering particles (fig. 10). In principle, a resuspension of all these paths is possible.

The particles reaching the ground are resuspended, accumulated at the surface or mixed into the soil through turbation or percolation water (HÖKE 2003a, LENNARTZ 2004, BLUME 2004). In urban-industrial agglomerations dust inputs can represent an important component of soil formation and make up a large proportion of fine soil constituents (HÖKE 2003a). The amount of urban PM_{10} -exposure actually reduced by soils is still unknown.

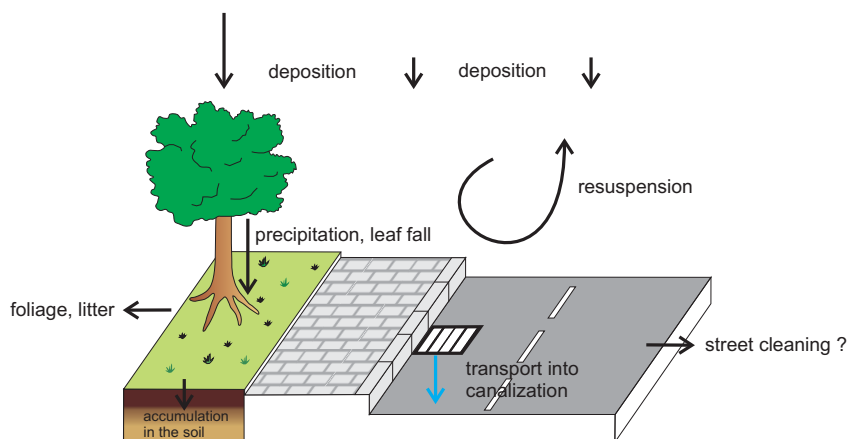


Fig. 10: Particle dynamics in urban areas. By dry and wet deposition dust is deposited on surfaces. The deposition rates of vegetated surfaces are higher than that of sealed surfaces. During precipitation events with sufficient intensity, part of the particles adhering to surfaces are washed into canalization or in adjacent soils. The resuspension from roads and sidewalks is particularly intensive in contrast to soils, favouring an accumulation.

In many studies it has been observed, that the PM_{10} loads in ambient air are in large parts due to the road dust resuspended by traffic (LENSCHOWET al. 2001, STERNBECK et al. 2002, LOUGH et al. 2005, THORPE & HARRISSON 2008, MARTUZEVICIUS et al. 2011). Even pedestrian activity can contribute to the resuspension of sidewalks (NICHOLSON 1988, SEHMEL 1980). Therefore, it can be assumed that, in comparison to plant covered non-traffic surfaces, roads and sidewalks favour a resuspension. It is undisputed, that technogenic materials such as asphalt, concrete or brick are not able to accumulate particles in the long-term. Although there is hardly any quantitative data on the deposition of atmospheric particles as well as resuspension from plant-covered soils, but in comparison to sealed surfaces they can be rated higher with regard to their air quality effects.

In many regions of the earth soils act as a dust source (HERRMANN et al. 2010). This process is particularly intense when the mineral soil is not protected by vegetation and moisture from prevailing winds. Since urban soils in Central Europe are usually covered with vegetation, it is assumed that particle release occurs to any significant extent only when the soil is fallow (e. g. industrial areas or arable soil) and under mechanical stress (e. g. from traffic, from construction activities or tillage in agriculture; FUNK & HOFFMANN 2010, FUNK et al. 2008, HÖKE 2003b, CARVACHO et al. 2004).

4 A model calculation: what happens if one hectare of soil is sealed?

In order to illustrate the previously described processes, the scenario, „What happens if one hectare of cropland soil is totally sealed?“ was quantified in this study. For this purpose the

climatic situation and the site-specific soils (Luvisols on loess) of the Filderebene in Stuttgart were considered. The results are shown in Table 3. Notes on the calculation basis of the scenario can be found in the long version of the project report.

Through plant biomass and soil organic carbon loss, the surface sealing of an area of one ha triggers 64,9 t CO₂-emissions and 7,5 t CO₂-equivalents of N₂O-emissions. Since there are no reliable findings on the effects of soil sealing and topsoil application, this calculation is accompanied by large uncertainties. Furthermore, the sealing leads to a loss of methane sink, the quantitative effect, however, is small compared to the two other greenhouse gases. On a local climatic level, the sealing is associated with a reduction of evaporative cooling of 8918 GJ per year. This excess energy becomes available to warm the surfaces and adjacent air masses, hereby increasing urban overheating. A calculation of the filtering and absorption potential for atmospheric particulates could not be performed due to poor scientific data.

In large parts, the positive effect resulting from a functional soil-vegetation system is provided by plants. Isolation and a pro rata assignment of effects on the soil and vegetation are not effective, since they constitute a functional unit. Given that soils act as a habitat for vegetation through a broad range of site properties, the habitat function is of great importance for climatic processes on all scales.

5 Outlook

Generally, it can be found that the climatic consequences of soil consumption and encroachments on terrestrial ecosystems so far received little attention from both, the general public and local stakeholders. This is hardly surprising for the global climate complex, because greenhouse-gases unfold their effect in the high atmosphere and lead to slow processes, indirect emissions occur off-site and the interactions only came into the scientific focus, with the emergence of the debate on global change. The impact at the level of the urban climate can be perceived more easily, since they occur instantaneous and in the localized environment of the encroachment. The integration of these issues into environmental planning has already been partially implemented through climate analysis maps. One should hope that in the planning process, the role of soil protection is also assessed with respect to the impact on the climate, because soil protection means climate protection. Against the background of predicted increases in atmospheric greenhouse gas concentrations and temperature extremes this topic will certainly gain in importance in future developments. Therefore, apart from the awareness for the need of protection of the soil functions considered up till now, awareness for soil climate function must also be created. This is one important aim of Urban-SMS and this study offers arguments and a system model in furtherance of that.

Table 3: “What happens, if 1 hectare of rank soil is sealed during the process of urban soil consumption?” For this purpose the climatic situation and the site-specific soils (Luvisols) of the Filderebene were considered.

factor	consequences of surface sealing (1 hectare)
global climate	
CO ₂	emission: 64,9 t CO ₂ (singular)
N ₂ O	emission: 7,5 t CO ₂ -equivalents (singular)
CH ₄	slight impairment of the methane balance (permanent)
urban climate	
cooling function	reduction: 8 918 GJ per year ≈ 283 kW (permanent)
filtration and sorption of PM10	no quantification

Many of the soil and climate protection measures to improve the balance of greenhouse gases have shown large synergy effects with regard to nature conservation (FREIBAUER et al. 2009, SAATHOFF & VON HAAREN 2011). Approaches to already existing legal actions concerning nature conservation to implement these measures are already abundant (SAATHOFF & VON HAAREN 2011). In practice the communal level is the level of realization. Concerning these actions, the environmental policy maxim “think globally, act locally!” applies more than ever.

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URBAN SMS Soil Management Strategy



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6.2.5 impacts of soil consumption on climate

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