Air pollution risk assessment on urban agriculture

17 August 2017

Master Thesis

by

Marthe ORTOLO

Spring Semester 2017

Supervisors:
Chris VAN DIJK
Jan-Eelco JANSMA
Satoshi TAKAHAMA

Acknowledgements

I am first deeply grateful to my three supervisors, Chris, Jan Eelco and Satoshi, for the support and feedback throughout my project work. The progress meetings we had every two weeks steered me in the right direction and allowed me to produce a higher quality paper. The passion and motivation they had for the project as being related to their own work were for me very inspiring.

A very special gratitude goes to Suzanne, Tanja, Arnold for receiving my spinach containers in their gardens for 3 months, but also for their curiosity and interest in the results.

With a special mention to Bert van Alfen for his kind instructions in the field. If I was a neophyte spinach gardener, I am now proud of being an expert on the topic.

I would also like to thank Tom Voorma, Frank Bakkum, Anke van Duuren for participating in my interviews and for the precious information about the policies and urban agriculture initiatives in their municipality.

Furthermore, I am grateful for the whole AGRO team for the support on my project but also for our pleasant discussions around Dutch and French habits, politics and much more.

A big thank you goes to my parents whom without none of this would have ever been possible. Thank you both for the psychological support, love and the funding. Last but by no means least, I am grateful for my siblings and closest friends, for cheering me up when I needed it and for having listened with interest to my daily talks on my babies (spinach) status.

Thanks for all your encouragement!

Executive summary

Urban agriculture has been gaining popularity the past decades: it brings citizens together, strengthens their synergy and intensifies their delight of living in greener cities. However, scientific researchers are not well-acquainted with the impact of urban environment and its poor air quality, on the food itself, which is also a source of preoccupation for the citizens. Indeed, they are eager to know whether it is safe for them to consume their own harvest with respect to the surrounding environment. As an illustration, in Amsterdam, the public's main concerns is related to the air planes flying above the gardens, the car's emissions in the streets, the shipping traffic, etc. The present report provides an analysis and evaluation of the risk assessment of air pollution on urban agriculture. In the first place, the current knowledge on air pollution risk on urban agriculture is assessed, investigating scientific literature. Second, interviews of policymakers help to evaluate the juridical status of urban agriculture in relation to the urban environment, estimating their awareness on the topic. With this in mind, I tackle the spatial planning of urban initiatives, paying attention to the choice of the location, observing if it is subjected to analysis, if there are regulations about soil and air pollution, etc. Third, information on the harvest pollutants' concentration is crucial for quantifying the risk exposure. Hence, I conduct a bio-monitoring program in Amsterdam, measuring pollutants' levels in plants. I grow spinach in pots with unpolluted standard soil, in three locations in Amsterdam and in Wageningen, as a rural reference point. Then, it is analysed for its heavy metal, nitrate and polycyclic hydrocarbons content. Lastly, I model an urban and a rural environment with the intention of visualising the dispersion of air pollutants underlining the importance of the design of the city.

Firstly, I observe that the literature, embracing both urban agriculture and air pollution together, is still scarce, especially when compared to literature concerning soil pollution. Yet, scientific studies show no exceedances of the legal limits for pollutants (cadmium, lead, nitrate) in food products, although they observe higher concentrations in urban areas compared to rural areas. Then, I discuss the corresponding lack of regulations about air pollution on foodstuff. Alas, the results of the interviews are based on three interviews over approximately fifteen persons contacted. However, all the respondents are aware of the possible risk, they are curious and request the results of this study. Next, concerning the results of the bio-monitoring, they show little impact of the urban air pollution on the crops. The contaminants' concentrations are low during the research period and similar between the sites, suggesting a global background pollution rather than a site-specific one. Yet, results are highly dependent on the meteorological conditions and one has to be aware that it is a short time study, sampling on a longer period would help drawing more accurate conclusions. Finally, the modelling provides an illustration of the air flow, specific to a neighbourhood of Amsterdam. The deposition of particles is highly influenced by the physical environment, and urban infrastructures can lead to increased accumulations at certain locations. Understanding better the air flow and pollutants deposition, in the case of urban farming, could become a strong argument for a greater spatial planning.

On the basis of the results, I give suggestions on how to improve the accuracy of the results. I believe that the methodology followed during the project gives a reliable global overview, tackling different aspects of air pollution on urban agriculture, from reviewing the literature to the scientific observations in the field and the modelling of the latter.

Marthe Ortolo Wageningen, 17 August 2017

Rapport de synthèse

L'agriculture urbaine est un sujet en vogue. Ces dernières années, de nombreux jardins communautaires se sont développés dans les villes européennes, peut-être telle une réponse à l'urbanisation grandissante et au manque de nature autour de nous. En effet, c'est un domaine attrayant qui apporte de nombreux bénéfices. Il intensifie les liens sociaux des citoyens tout en améliorant leur qualité de vie. Toutefois, j'ai remarqué un manque de connaissance scientifique envers l'agriculture urbaine et la pollution spécifique à la ville, surtout liée à la qualité de l'air. Un exemple concret aux Pays-Bas est la présence de l'aéroport multi-national, à 10 km à peine du centre d'Amsterdam. Les avions décollent et atterrissent au-dessus de la ville. C'est ainsi que je me suis interrogée sur le risque de consommer les produits maraîchers qui grandissent aux pieds de l'aéroport. Ce rapport présente donc une analyse et évaluation des risques de la pollution de l'air en milieu urbain, en relation avec l'agriculture. En premier lieu, je décris l'état actuel de la recherche scientifique à ce sujet. Ensuite, des décideurs politiques sont interviewés afin d'évaluer le statut juridique de l'agriculture par rapport à l'environnement urbain. J'estime leur prise de conscience sur le sujet, les questionnant sur les régulations face à l'aménagement du territoire. De plus, pour quantifier l'exposition au risque, il est simple de mesurer la concentration en polluants dans les produits issus des récoltes. Par conséquent, je réalise un programme de bio-monitoring à Amsterdam, où des plantes sont cultivées en pot, avec un sol standard, non pollué, puis analysées pour leur contenance en métaux lourds, nitrate et hydrocarbures. En dernier lieu, je modélise et simule la dispersion et la déposition des polluants atmosphériques, dans le cadre d'un environnement urbain, en utilisant l'analyse numérique de la dynamique des fluides.

Concernant les résultats, je remarque premièrement que la littérature, sur l'agriculture urbaine et la pollution de l'air, est encore limitée. Cependant, les études scientifiques existantes ne montrent pas de dépassement des limites légales de polluants dans les produits maraîchers, bien qu'ils observent des concentrations plus élevées dans les zones urbaines, par rapport aux zones rurales. Puis, je discute de l'absence de réglementation relative à la pollution de l'air sur l'emplacement des jardins urbains. Hélas, les résultats des interviews sont basés sur trois entretiens malgré une quinzaine de personnes contactées. Cependant, tous les répondants sont conscients du possible risque, ils sont curieux et requièrent les résultats de cette étude. Enfin, les résultats du bio-monitoring montrent peu d'impact de la pollution de l'air urbain sur les cultures. Les concentrations des polluants dans les épinards sont similaires entre tous les sites et faibles sur toute la période, suggérant une pollution générale plutôt que spécifique à l'emplacement. Les résultats dépendent fortement des conditions météorologiques et il est important de préciser que c'est une étude de courte durée. Un échantillonnage sur une période plus longue aiderait à tirer des conclusions plus précises. Cependant, les résultats sont conformes aux attentes basées sur la littérature. Enfin, la modélisation permet d'illustrer la circulation de l'air dans le contexte spécifique d'Amsterdam. Cette analyse additionnelle est un atout majeur au bio-monitoring. La déposition des polluants étant dépendante du contexte physique, elle peut être accrue lors d'un environnement non favorable et la modélisation est un puissant outil pour une planification du territoire de bonne qualité.

Sur la base des résultats, des suggestions sont apportées sur la manière d'améliorer leur précision. La méthodologie suivie pendant le projet présente un portrait complet, abordant divers aspects de l'évaluation du risque de pollution atmosphérique sur l'agriculture urbaine : de l'étude des connaissances scientifiques à ce sujet, au bio-monitoring et à la modélisation.

Marthe Ortolo — Wageningen, le 17 août 2017

Contents

1 Introduction

1.1 Urban Agriculture: definition, history, potential and risks

Urban agriculture (UA) is defined as the production of food in urban areas (Veen, 2015). The international network, Resource Centres on UA and Food Security (RUAF) provides a detailed definition of the different categories of UA, going from the non-commercial purposes with micro farming (e.g. private gardening on balconies, on a rooftop or simply in a private garden) to market oriented UA with multi-functional UA businesses that combine different activities, that are if possible in synergy (Atelier GROENBLAUW, 2017). Multi-functional agriculture aims at restructuring the farm, beyond the industrial model, and adapting it to the new needs of the post-Fordist society, adding a consumption oriented component (e.g. producing organic food), recreational opportunities, etc (Zasada, 2011). Another way of defining UA is to link it to the urban economy and eco system in contrast to rural agriculture (RA). If the definition of urban, peri-urban area is sometimes difficult to apply, there is a real distinction between RA and UA from the integration of UA to the local urban economy (Bakker, Dubbeling, Guendel, Koschella & de Zeeuw, 2000, Thematic Paper 1). While the international definition tends to add peri-urban areas in the urban farming definition, in the Netherlands, it is restricted to the city limits (van der Schans, 2010). To delimit them, some studies use the population size, density thresholds or official boundaries of the city (Bakker et al., 2000, Thematic Paper 1). In this project, the focus was on non-commercial community gardens, defined as a plot of land in an urban area, cultivated individually or communally by a group of people from the direct neighbourhood or the wider city (Veen, 2015). Amsterdam boundaries were not strictly defined, the urban and peri-urban gardens were both evaluated as part of UA.

UA is often described as an emerging/trendy concept but different forms of UA have been existing since the early rise of urban centres. Settlements occurred in the Neolithic period between 6000 and 4000 BC at locations where the climate, soil, water and topography were favourable, which led to high agricultural productivity (Steel, 2008). Then, by early medieval times, a new relationship emerged between urban and rural areas where cities relied on the countryside to feed them (Steel, 2008). In 1800 only 3% of the population lived in cities, the past 50 years endured dramatic changes with a predominantly urban population since 2006. The cities have been asking for a more diversified and nutritious diet based on meat (Steel, 2008). World War I and World War II gave a temporary boost to UA, as being one solution to reduce the pressure on food production and a tool to achieve food security (Bakker et al., 2000, Thematic Paper 2). Lastly, the late 20^{th} century has experienced an unprecedented revival for UA, taking a whole different meaning. The concept has taken a new lease, with new purposes. It is considered as a way to achieve sustainability in cities (Prov. Dessein & de Krom, n.d.), to enhance exchanges within a neighbourhood, preserve the living environment, etc. Cities have a great potential for food growing. Berlin has 80 000 community gardens and a long waiting list for new ones. In Mali, Bamako is self-sufficient in vegetables (Bakker et al., 2000, Thematic Paper 2). One of the key facts about UA is that a large amount of food is produced in cities and suburban farms, which supply 1/4 of the world's urban population, which represents approximately 700 million city dwellers (FAO, 2015).

UA shows a high potential for the urban population, the economy and the environment, all together leading towards a healthier life style. Food, health and environment are some important values linked to UA as well as care and well-being (Jansma, Chambers, Sabas & Veen, 2015). Indeed, UA is associated with increasing social interactions in community gardens. It is also related to more physical activities, with the creation and maintenance of the garden, which can be further connected to better health (Brown & Jameton, 2000). However, UA is also subject to risks due to environmental conditions in cities that differ from conventional agricultural areas (Bakker et al., 2000; Craul, 1985). The air quality in cities results from interactions between natural and anthropogenic environmental conditions: with traffic, industrial emissions, global background pollution and meteorological conditions. Eating food grown in urban gardens may be harmful for human consumption due to air and soil pollution.

1.2 Objectives

UA took a new turn these past decades due to the needs of the citizens to reconnect with nature but also with the improvement of technologies, etc. However, the knowledge on the uptake of air pollutants by plants and successively on its impact on public health once ingested, is still scarce. In comparison to soil pollution related to food consumption, the air pollution topic seems to be less obvious and familiar to the public. Yet, within a city, many sources of pollution are present: traffic, heating, industries, etc. Many pollutants characterise urban pollution: particulate matters, heavy metals, hydrocarbons, nitrates, etc, but only some of them accumulate in plants.

This master thesis aimed at answering the question: "Is there any risk, in relation to human health, of air pollution in urban community gardening?"

The first part of the thesis consisted of reviewing the current knowledge on UA and air pollution. Furthermore, some information on the awareness of the policy makers and politicians in the main cities of the Netherlands was gathered. Practical experiments are pursued in Amsterdam where spinach was grown in order to respond to the hypothesis of a potential risk of air pollution on urban farming. Last but not least, Computational Fluid Dynamics (CFD) modelling complemented the experiments, helping to understand the behaviour of the air pollutants in some configurations specific to the Netherlands.

1.3 Content of the report

1.3.1 State of the art

Firstly, this report presents the state of the art of the current knowledge on the effect of air pollution on UA. Literature assessing both subjects combined is still scarce, hence the importance of building bridges between the two. There are three main risks of gardening in an urban environment: soil, water and air pollution. Each of them is evaluated but the risk of air pollution is further elaborated. The air pollutants are described as being divided into three categories: the ones that are not accumulated in plants, the ones that are transport-vectors of pollutants and the pollutants taken up by the plant. The physical processes of dispersion and deposition of the air pollutants are assessed as well as the mechanisms of pollutant uptake by plants. Finally, UA governance, in relation to its risk is presented and food standards regulating pollutant concentrations are given.

1.3.2 Policies in the Netherlands, awareness of citizens and policy makers

An important part of the thesis was to depict the food safety policy strategies on air pollution. Policy makers and geographers involved in the municipalities and in the urban development of the cities were interviewed. Differences in the awareness between municipalities and its citizens could be drawn. In Amsterdam, Rotterdam, The Hague and Groningen, websites registering the urban green initiatives are emerging. Municipalities encourage these initiatives, providing directives for the new initiatives, subsidies and/or materials.

1.3.3 Bio-monitoring and modelling

This study describes the results of the spring, early-summer 2017 bio-monitoring program in urban/peri-urban Amsterdam and in Wageningen, in the Netherlands. Spinach is a relevant bio-accumulator for diverse pollutants. Accumulators are not as sensitive as bio-indicators to ambient phytotoxic compounds but they accumulate gases and particles in or onto their leaves. The aim of this program is the early detection of the possible effects of urban atmospheric pollutants on the quality of the crops of community gardens. The study focuses on components that are characteristic of urban pollution: the heavy metals cadmium (Cd), copper (Cu), mercury (Hg) and lead (Pb), nitrate and polycyclic hydrocarbons (PAHs).

To complement the experimental program, the local environment of Amsterdam is described. The Dutch National Institute for Public Health and the Environment (RIVM) data are used to draw up statistics on the air pollutants occurrence in Amsterdam. Further meteorological parameters are also computed, among which, the average temperature, the average humidity and global solar radiation. All these data and the 2D design of urban Amsterdam are given as input to a CFD model, Ansys Fluent. The use of CFD simulations highlights how the air flows and how the wind velocity is altered in urban areas. The potential scope for CFD application in this project is related to its high efficiency of tracking particles in the flow. To mimic the concentration of Amsterdam's background and roads traffic emissions, injections of particles are simulated and then tracked to observe their deposition onto surfaces representative of urban community gardens (e.g. with high roughness length).

2 State of the art

2.1 Risks of gardening in an urban environment

There are three possible routes of trace metal accumulation in crops, the soil, the water and the air. The water and soil can both influence the results of the bio-monitoring, therefore the importance to deepen all the risks.

2.1.1 Risk of soil contamination

The soil pollution in urban areas is a topic already well-documented (Hazelton & Murphy, 2011; Meuser, 2010). The soil in an urban environment exhibits very different characteristics compared to one in the countryside. Mainly due to human activities, the soil is subject to mixing of materials while being removed, stocked or piled; filling (to raise the level of a surface) and contamination from (historical) industrial activities, heavy traffic, etc (Craul, 1985). This results to a high vertical and spatial variability expressed by the presence of other anthropogenic elements and contaminants such as solid waste with masonry, wood and paper, glass, plastic, metals, asphalt and organic garbage. When these are mixed with the soil they may affect its physical, chemical and biological properties (Craul, 1985). Cadmium and lead are two major contaminants in urban soils. Some solutions can tackle these issues like raising the pH and maintaining it to a high level; adding manure or compost in order to immobilise heavy metals (Bakker et al., 2000, chapter 2). Citizens may use directly the soil that they have in their garden or amend pots or beds with commercial garden soil. Some studies have shown higher accumulation of pollutants when using commercial soil, it maybe due to the use of compost in the urban soil beds that increases metal solubility (Säumel et al., 2012). To conclude, soils in cities are subjected to potential risks of contamination. They can differ significantly on a spatial scale and it is important to study the quality of the soil to prevent contamination on UA. To avoid contamination, a solution can be to use raised beds with controlled (e.g. commercial) soil.

2.1.2 Risk of water contamination

Four types of water can be used for watering plants: tap water, rain water (e.g. collected on roofs), surface water (e.g. ponds, lakes) and underground water (e.g. by pumping water). Drinking water in the Netherlands has a very good quality so it should not be a problem in terms of heavy metals trace for example (Vewin, 2017). Most of the gardens collect the rain water in order to grow food. Harvesting water is a sustainable solution compared to the use of tap water. It also responds to the issue of the water run off in urban areas, due to decreased permeability of soils (Bakker et al., 2000, Thematic Paper 2). On the other hand, it is a sort of double-edged sword, as while the water travels across the urban environment, it accumulates pollutants (e.g. heavy metals and trace organic pollutants on roofs) (Meera & Ahammed, 2006). The quality of the surface water (rivers, lakes, sea water) fluctuates in the Netherlands. Most of the water bodies do not meet the requirements, chemically (as given by the European Water Framework Directive (WFD)) and ecologically (Environmental Data Compendium, 2016). In the Netherlands, the quality of the groundwater is good in 60% of the water bodies. It depends on the ground water table level, the deeper it is the more purified the water is. However, high levels of nitrates linked to an over-use by some farmers represent an issue for water (Government of the Netherlands, n.d.). To summarise, the quality of water depends on its origin. Tap water and underground water have a high quality and are less subjected to pollution compared to surface and rain water. Hence, using tap water assures a good quality, avoiding contamination. Yet, the rain water contamination is a variable that can not be avoided.

2.1.3 Risk of air contamination

The impact of air pollution on UA has not been investigated as much as soil contamination impact on UA (refer to the sections 4.1 and 5.1). The European Commission science hub supports the importance of having knowledge on the source of air pollution. The following section will describe with further details the urban air pollutants and their sources.

2.2 Air pollutants

In Europe, air pollution has been decreasing over the past decades but it is still an important field of study as numerous contaminants are harmful to both public health and the environment (European Environment Agency, 2016). At the European Union scale, the Directive 2008/50/EC was adopted by the Council and the European Parliament in 2008, they fixed long term objectives (for 2020) with the Clean Air Policy Package adopted in December 2013. It aims at improving the air quality, lowering the global warming impact (European Commission, 2016). Jimmink et al. (2014) provide a full description of the sources of air pollution, of the trends of emissions in the Netherlands. The national Pollutant Release and Transfer Register (PRTR) is a national database that monitors all emissions, in the air, water and soil of pollutants and greenhouse gases (GHG). It uses national and international emission factors.

Figures 11a and 11b (in Appendix A) give the emissions of SO_x, NO_x, NH_3, PM_{10}, $PM_{2.5}$, NMVOC (non-methane volatile organic compound), CO, CH_4, BC, heavy metals (As, Cd, Ni, Pb, Hg) and benzo[a]pyrene (BaP) over the 2000-2014 period, according to the sector of emission in Europe. We can largely distinguish some features such as the great decrease of Pb in the transport sector (Fig. 11b), due to the removal of Pb from gasoline and the high variations in BaP emissions in the industrial sector, with a global increase from 2000 to 2014. However, for BaP, the uncertainties in the reported emissions are high, being globally underestimated due to missing data for several countries. The states contributing mostly to BaP emissions in UE are Poland, Germany and Roumania (European Environment Agency, 2016) with the domestic combustion of coal and wood.

The main urban air pollutants are presented separately in the next sections, distinguishing the ones that are not accumulated in plants (2.2.1), the ones that serve as transport vectors of elements (2.2.2) and the ones that accumulate in plants (2.2.3). For each pollutant, a chemical/physical/biological description is shortly given. Then, the sources of the air pollutants are specified with a focus on the Netherlands and its emissions. Finally, the effect of each pollutant on plants is briefly assessed. In addition, the mechanisms of the plants' pollutant uptake are further described in the section 2.4.

2.2.1 Pollutants not accumulated by plants

Ozone (O_3)

Ozone is a strong oxidant, formed by photochemical reactions of precursors pollutants as NO_x and volatile organic compounds (VOC) (European Environment Agency, 2016). Traffic is the main source of O_3 precursors. However, unlike most of the pollutants, O_3 is more scarce in urban areas. Indeed, O_3 can be degraded by NO_x and this reaction occurs more often in cities due to a higher concentration of NO (European Environment Agency, 2016). The Directive 2008/50/EC gives a Target Value Threshold (TVT) for O_3 concentration of 100 $\mu g/m^3$ (8-hour mean) that should not be exceeded more than 25 days per year. In the Netherlands, the previous TVT (of 120 $\mu g/m^3$ (8-hour mean)) was never exceeded in 2012 and the annual mean of 8h-max was about 60 $\mu g/m^3$ in 2012 (results from the latest report of the European Environment Agency (2014)). O_3 also affects vegetation and ecosystems, especially during their growing stage. O_3 enters the leaves through the stomata by normal gas exchange (Darrall, 1989). When a plant is exposed to high concentration of ozone, it is subjected to foliar chlorosis or necrosis (Klumpp, Fomin, Klumpp & Ansel, 2002; Markert, Breure & Zechmeister, 2003).

Carbon monoxide (CO)

Carbon monoxide is naturally present in the environment. Photochemical reactions in the troposphere generate about $5 * 10^{12}$ kg/year, which is the largest source of production of CO (Weinstock & Niki, 1972). The population is exposed to CO from indoor micro environment sources like cooking and heating with domestic gas, wood fire, tobacco smoke, etc (Raub, 2004). However, motorised road transport is the main source of pollution where CO is emitted due to incomplete combustion. In inner street canyons, high values are often met, due to stagnant traffic and poor aeration. In the Netherlands, the emissions have been decreased by half since 1990, from about 1150 Gg CO in 1990 to 600 Gg CO in 2012 (European Environment Agency, 2014). In plants and when there is light, CO is fixed mainly in serine and follows the serine pathway to sucrose. CO can also be converted to carbon dioxide (CO_2) and be metabolised as such. The distribution of CO and CO_2 fixation is more or less similar, it depends on CO_2 concentration and the presence of light (Bidwell & Fraser, 1972). Nonetheless, high levels of CO_2 do not increase the plant growth, it would rather cause the stomata to close by 20 to 40% and reduce the transpiration water loss, in diverse plant species (Barnaby & Ziska, 2012).

Sulfur oxides (SO_x)

SO_x are composed of sulfur and oxygen molecules. The predominant form of SO_x in the lower atmosphere is the sulfur dioxide (SO_2). Sources of SO_x are burning fuels or roasting metal sulfide ores. However, the major source of SO_x are volcanic eruptions, accounting for 35 to 65% of the total SO_x emissions (World Health Organization, 2003). In the Netherlands, SO_x emissions decreased by 82% during the 1990-2012 period, this reduction occurred in the energy, industry and transport sectors. Nowadays, it is the industry, energy and refining sectors that are responsible for the largest national SO_2 emissions (94%) (Jimmink et al., 2014). SO_x are harmful to the environment. Under fumigation of SO_2, plants cannot perform photosynthesis and exhibit stomatal closure (Darrall, 1989). Darrall (1989) observed that the sensitivity was dependent on the sensitivity of the species, the gas concentration, the environmental conditions (e.g. under low light intensity, the sensitivity is lower). Interactions with other pollutants modify also the plant response, notably with additional elevated CO_2, stomata naturally close to increase plant water use efficiency and limit the response to SO_2 pollutant. Finally, effects on the distribution of the plants assimilation have been observed, with changes in root-shoot ratios (Darrall, 1989).

Gaseous nitrogen compounds

The most significant atmospheric forms of nitrogen from anthropogenic activities are nitric oxide (NO) and nitrogen dioxide (NO_2) (Robinson & Robbins, 2012). Yet, ammonia (NH_3) is also relevant as it is mainly related to agriculture.

- Nitrogen oxides (NO_x) and Nitrous oxide (N_2O)

  NO_x include NO and NO_2. NO_x and especially N_2O originate mainly from the use of fertilisers in agriculture. As for the SO_x, the NO_x national emissions were decreased by 57% during the 1990-2012 period (Jimmink et al., 2014). The main contribution to this decrease came from the energy and road-transport sectors, with the introduction of the three-way catalyst for gasoline (decrease in NO_x from 141 Ggin 1990 to 27 Ggin 2012). Emissions were reduced but it was also counterbalancing an increase in number and transport distance of vehicles (Jimmink et al., 2014).

- Ammonia (NH_3) & Ammonium (NH_4)

  The agricultural sector accounts for 93% of total NH_3 emissions in EU-28, 85% in the Netherlands (Jimmink et al., 2014). It is related to intensive agriculture, with high rates of fertiliser manufacture and application, livestock manure, etc. However, the emissions have considerably decreased compared to 1990 with the enforcement of policies, banning manure surface spreading, setting maximum application standards for manure and synthetic fertilisers, etc, but also thanks to the decreasing animal population (Jimmink et al., 2014). In urban areas, traffic can also contribute to NH_3 emissions but in a much lower magnitude compared to chemical industry emissions or emissions from fertiliser application, livestock wastes, compost, etc (S. Wang et al., 2015). Most of NH_3 is deposited quickly near to the sources of emission. The gas has a short half life of around 7 h and is highly reactive (Pearson & Stewart, 1993; Robinson & Robbins, 2012). NH_3 reacts with acidic species (e.g. SO_2, NO_x) and forms ammonium-containing aerosols, it contributes particularly to $PM_{2.5}$ formation (S. Wang et al., 2015). The deposition can be in the form of gaseous ammonia, aqueous form as the ammonium ion or as an aerosol. Ammonia can induce plant damage such as yellowing of the leaves, necrosis, etc. It also affects plant growth and inhibits it completely above a certain level (Pearson & Stewart, 1993).

Methane (CH_4)

Methane is one of the primary GHG. More than half of the total emissions of CH_4 in the Netherlands comes from the agricultural domain (61% in 2012), from livestock production, notably ruminants, from agriculture soils (use of inorganic fertilisers, livestock manure, etc), field burning, etc. In cities, CH_4 comes from natural gas handling systems and waste disposal facilities (Hopkins et al., 2016; Jimmink et al., 2014). It is a scientific debate whether green plants are a source of CH_4 (Dueck & Van Der Werf, 2008). Estimations differ greatly on the global CH_4 emissions by vegetation, from 10 to 30% of the global annual emissions. However, the mechanisms of such emissions are still questioned, varying from plant species, affected by atmospheric and soil conditions, etc. Some plants are also net absorbers of atmospheric CH_4, e.g. Sphagnum spp. mosses in symbiosis with partly endophytic methanotrophic bacteria consume CH_4. CO_2 is produced from the oxidation of CH_4 and then fixed during photosynthesis

(Schultz, 2013). Sundqvist, Crill, Mölder, Vestin and Lindroth (2012) assessed the effect of boreal species (birch, spruce, pine, and rowan trees) on atmospheric CH_4 and the influence of photosynthetically active radiation (PAR), temperature, photosynthesis rate, and ultraviolet radiation levels. They observed a positive correlation between an increase in PAR and CH_4 uptake for three of the four species and concluded that plants might be an underestimated sink of atmospheric CH_4 rather than a source.

2.2.2 Transport vectors pollutants

Particulate matter (PM)

PM consists of a mixture of solid particles and liquid droplets suspended in the air, made of organic and inorganic substances (Bergauer, Janknecht, Wiseman & Zereini, 2011). These particles are divided into three categories according to their size:

- PM_{10}

  It is the coarse fraction of the PM, from 2.5 to 10 µm. These particles are composed of heavy metals, sulfate, nitrate, ammonium, organic material, PAHs, dioxins and furans (Federal Office for the Environment, Switzerland, 2016). These particles contain dust from roads and industries. PM_{10} are the major contributors of all aerosols, in terms of mass and volume. They have a low residence time in the atmosphere (1-7 days), due to rapid sedimentation (Lagzi, Mészáros, Gelybó & Ádám Leelőssy, 2013).

- $PM_{2.5}$

  Also called fine particles, they are mostly secondary formed aerosols ('aerosol' being the generic term for the particulate/air mixture), combustion particles and re condenses organic and metal vapours. $PM_{2.5}$ contain often PAHs, PCDDs, PCDFs, polychlorinated biphenyls (PCBs) and heavy metals (Bergauer et al., 2011; Dzierżanowski, Popek, Gawrońska, Sæbø & Gawroński, 2011).

- $PM_{0.1}$

  Ultra fine particles (UFP) behave more like gas molecules. They are deposited by diffusion. By number, they constitute the majority of the aerosols. However, in terms of mass, their contribution is only a few percent of the total aerosol mass (Lagzi et al., 2013).

PMs originate from road transport with the combustion process, rail transport (abrasion), agriculture and forestry (combustion), industry, commerce, construction sites, furnaces (when wood is used as fuel). Secondary formation can also occur from SO_2, NO_x, NH_3 and VOCs (Federal Office for the Environment, Switzerland, 2016). If PM_{10} originates mainly from local vehicular traffic (direct emissions and re-suspension) $PM_{2.5}$ is mostly related to regional and long-range transported particles. In the Netherlands, PM_{10} emissions were reduced by 62% during the 1990-2012 period, due to cleaner fuels in refineries and due to the side effect of the parallel SO_2 and NO_x decline. For the same reasons, $PM_{2.5}$ emissions were also reduced by 72%, going from about 56 Gg in 1990 to 13 Gg in 2012 (Jimmink et al., 2014). In plants, PMs cover leaves and reduce light penetration, blocking the opening of stomata. PM bounded to organic pollutant may be of a lipophilic nature, and can, therefore, enter the wax layer that covers the leaves and young twigs (Janhall, 2015).

2.2.3 Relevant air pollutant components up-taken by plants

Dioxins

Dioxins are highly toxic chemicals. 'Dioxins' is the name given to the family of structurally and chemically related polychlorinated dibenzo para dioxins and furans (PCDDs, PCDFs) (World Health Organization, 2016). Dioxins are formed unintentionally as a by-product of industrial processes involving chlorine (e.g waste incineration, chemical and pesticide manufacturing) (van Dijk, van Doorn & van Alfen, 2015; World Health Organization, 2016). PCDD and PCDF can be found in two fractions: vapour and particulate phase. The vapour phase can be taken directly by the leaves of the plant (via the stomata and the wax layer) while the particulate phase can be deposited (see 2.2.2) (Chrostowski & Foster, 1996). Photolysis and volatilisation are also two phenomena that are most likely to occur as most of the dioxin-like compounds are photoreactive. Plant dioxins uptake is an exposure route for the livestock (Chrostowski & Foster, 1996). They tend to accumulate in the fatty tissue of animals and therefore appear in the food chain. The source of exposure is our diet. To reduce it, one should eat less meat and dairy products (World Health Organization, 2016). They can cause cancer, reproductive and developmental problems, etc. In the Netherlands, the long term dietary exposure has been decreasing the last decade but the uncertainty on the results of several studies is quite high. Indeed, the sampling size can vary but another factor is the change in the Dutch diet, from full-fat milk to semi-skimmed and skimmed products containing fewer dioxins (Boon, te Biesebeek, de Wit-Bos & van Donkersgoed, 2014).

Heavy metals

The term "heavy metals" encompasses the group of metals and metalloids having a density greater than $4 \pm 1 g/cm^3$. They can be found naturally in the environment, in soils, rocks, sediments, waters and microorganisms. Some of the heavy metals are essential nutrients but most of them can be toxic at large concentrations. Heavy metals are persistent in the environment, they cannot be biodegraded. Some procedures to control the pollution are physical removal, detoxification, bio-leaching, and phytoremediation; it reduces the availability, mobility and toxicity of the metals (Khan, Zaidi, Goel & Musarrat, 2011, Chapter 1). Eminent sources of atmospheric emissions are the burning of fossil fuel to generate energy (V, Ni, Hg, Se, Sn), automobile exhaust (Pb), insecticides (As), manufacturing of steel (Mn, Cr), smelting (As, Cu, Zn), etc. The main contaminants, being relevant for an urban atmospheric pollution risk assessment, are:

- Cadmium (Cd)

  Cd is widely dispersed in the environment through mining and smelting, the usage of phosphate fertilisers and various industrial uses (NiCd batteries, plating pigments, stabilisers in plastics) (Tucker, 2011). It is also correlated to traffic exposure, as added to fuels as preservatives (Cd among other metals: Ag, Ce and Ba) (Antisari, Orsini, Marchetti, Vianello & Gianquinto, 2015). In the plant, Cd can be taken up via the stomata. It is very mobile and can be stored in different parts of the plants (e.g. roots, stems and seeds) (van Dijk et al., 2015).

- Copper (Cu)

  If the health concern is more associated to soluble Cu compounds getting into drinking water and certain foods (shellfish, organ meats, legumes, nuts) (Agency for Toxic Substances and Disease Registry (ATSDR), 2004), important sources of atmospheric Cu intake are brake wear, automobile emissions, soil and coal via inhalation. Airborne Cu is associated with solid PM (N. D. Kim & Fergusson, 1994). In the Netherlands, brake wear contributes for about 80% of the atmospheric Cu emission (Hulskotte, van der Gon, Visschedijk & Schaap, 2007). Agriculture and overuse of fertilisers, with the application of Cu sulphate, can also contribute to Cu accumulation in plants (Antisari et al., 2015).

- Lead (Pb)

  The removal of Pb from gasoline made the emissions decreased by 95% in the Netherlands, the remaining emissions are emitted by the industry sector (Jimmink et al., 2014). In parallel to the adoption of unleaded gasoline, lead concentration in plant tissues has been decreasing significantly (Antisari et al., 2015).

- Mercury (Hg)

  Mercury is a persistent pollutant in the environment that accumulates in fish, animals which become part of the food chain. It enters naturally the environment with the breakdown of minerals in rocks and soil. Another source of release of Hg is resulting from human activities, with the mining and burning of fossil fuels (accounting for 80% of the Hg released from human activities), due to the use of fertilisers, fungicides and municipal solid waste (for about 15%) and from industrial waste water (5%). However, the Hg level is known to be very, very low in the atmosphere (US Department of Health and Human Services, 1999). Atmospheric Hg can accumulate in leaves (Boening, 2000; Ericksen et al., 2003; Niu, Zhang, Wang & Ci, 2011). Hg also accumulates in roots but many studies related it to the soil concentrations. In higher plants, Hg exposure can reduce photosynthesis and transpiration, water uptake and chlorophyll synthesis (Boening, 2000). For some species, as wheat, Niu et al. (2011) observed high correlations between Hg concentration in upper stems and air Hg concentrations (Hg being fumigated). Similarly, the crop foliage Hg concentration was highly correlated with the Hg air concentration.

In the Netherlands, even though the emissions have been reduced, the concentrations of heavy metals in the environment are not decreasing. A few assumptions on this results are first the geological speed of disappearance of heavy metals; the effects of diffuse emissions that are not recorded (like for fertilisers); dumping on landfill sites, etc (van der Voet, Guinée & Udo de Haes, 1998). Some plants can resist to pollution, but some are also very sensitive to high levels of specific heavy metals. On shorter vegetative cycle, the content of metals may be lower than when a plant persist in a field (Antisari et al., 2015).

Polycyclic aromatic hydrocarbons (PAHs)

PAHs are aromatic substances consisting of inter connected fused rings, without alkyl groups. The range of PAHs goes from a monocyclic molecule to a nine-ranged structure. The increasing number of rings coincides to a decreased mobility and hydrophilicity. Small PAHs correspond to the ones with 6 or less aromatic rings, above 6, they are called large PAHs (Shen, 2016). PAHs have a high capacity to sorb organic pollutants but it is also dependent on the presence of organic matter or free lipids that could block the pores. Previous studies on the monitoring of the air quality on traffic pollutant diffusion have shown that the prevailing compounds in the PAH due to road traffic are: phenanthrene (PHE), fluorene (FLU), pyrene (PYR), chrysene (CHR) sometimes accounting for 80% to 85% of the total (Klumpp et al., 2002). PAHs can be either emitted from an anthropogenic source or by a natural one. Natural sources of PAHs are oil steeps, crude oil deposits, forest fires, volcanoes, erosion of sediments, etc. Anthropogenic sources include thermal alteration of organic matter or incomplete combustion of organic matter (incinerators, other industrial processes; automotive emissions, cigarette smoke, barbecues, etc). Nowadays, the major production of PAHs is due to human utilisation of petroleum products, incomplete combustion of fossil fuels, biofuels (Shen, 2016; Stogiannidis & Laane, 2014). Vegetation removes PAHs from the atmosphere (Simonich & Hites, 1994). Simonich and Hites (1994) measured the concentrations of 10 PAHs in vegetation in Indiana, USA. They found higher PAHs concentrations in plants with high lipid content. They also observed a dependence between the atmosphere and the vegetation, with high vegetation PAH concentrations at low ambient temperatures (spring and fall), and low concentrations at high ambient temperatures (summer). Indeed, at lower temperatures, the sorption of organic pollutants on plant surface prevails. Secondly, the lipid content is often risen during winter, adding another potential explanation to higher concentrations in cold seasons. The scavenging of micro pollutants from the atmosphere by plants may be a risk for both human and animals by introducing xenobiotics into food webs (Franzaring & Eerden, 2000).

Even though several pollutants characterise urban environments, not all are relevant for the atmospheric uptake by plants: CO, SO_X and gaseous N compounds are emitted by road transport, energy, industry sectors, etc, but they are not accumulated in plants. However, some of them can damage (and inhibit) the plant (growth) when high concentrations are reached. Dioxins are accumulated in plants but the risk of ingestion occurs later on in the food chain, via meat/dairy products consumption. On the other hand, heavy metals and PAHs accumulate in plants and therefore might pose a risk when consumed. Particulate matters are a transport vector of the previous compounds.

2.3 Dispersion and deposition of air pollutants

2.3.1 Dispersion

The dispersion phenomenon is related to transport and dilution of air pollutants, from a large scale with regional winds to more local winds and their interaction with the landscape (e.g. street canyons). In an urban area, the surface roughness of the buildings accounts for the description of the surface texture effect, but other parameters such as vegetation, also influence the dispersion, here by decreasing temperatures. Meteorological variables also interact with the system. For example, the near surface boundaries, are influenced directly by convective exchange processes with solar radiation, daily temperature fluctuations, etc (Janhall, 2015). A typical urban system is a street canyon. When the wind is parallel to the street canyon, the flow is channelled through the canyon. When it is perpendicular to the street canyon, vortices are created. The number of vortices is dependent on the street buildings design. The larger the height/width (H/W) ratio, the higher the number of vortices (De Giovanni et al., 2015).

2.3.2 Deposition

There are two kinds of deposition, dry and wet deposition. If the dry deposition is a continuous process, the wet deposition occurs only when there is a rain event.

- Dry

  There are two types of dry deposition: by turbulent diffusion for the gases and small particles and by sedimentation for the large particles. The deposition of gaseous particles depends strongly on the season and on the vegetation type. For instance, Lagzi et al. (2013) observed higher rates of ozone deposition during day time compared to night time for forests. Grasslands present similar but attenuated patterns. They related it to weak turbulence compared to the unstable day time Atmospheric Boundary Layer (ABL). Furthermore, during the day, the environmental conditions for exchange processes through the plants are optimal (e.g. photosynthesis is possible only during the day, open stomata). The air humidity is also a decisive parameter as particles are inclined to attract water droplets. The wind speed has a controversial influence on the deposition of particles. In the direct vicinity of emitters, the highest pollutant concentrations are found. Implementing vegetation close by the emission sources is a way to maximise the plant filtration but it is dependent on the structure of the environment. Indeed, it could also lead to increased deposition due to a reduction in near-surface air exchange. The dry deposition of aerosol particles is highly dependent on their size. The larger they are (10-100 µm), the more they will settle down gravitationally (eddy diffusivity becomes important). Impaction and intersection affect the deposition of PM larger than 0.5 µm. UFPs (< 0.1 µm) act like gas particles and are therefore deposited by diffusion (Brownian motion). These PM can enter the leaves stomata (Litschke & Kuttler, 2008). However, after a certain amount of absorption retention, the particles saturate the stomata and the efficiency of adsorption is decreased (Chen et al., 2015).

- Wet

  Wet deposition consists in: in cloud scavenging (rain-out) or below-cloud scavenging (washout). Wet deposition is the major sink process of aerosol particles (Lagzi et al., 2013).

The dry deposition velocity can be calculated easily as the inverse of the resistance to deposition R_{tot} (Eq. 1) [Davidson and Wu (1990) in Janhall (2015)]. R_a corresponds to the aerodynamic resistance, R_b, the boundary resistance and R_c the surface (canopy) resistance.

$$v_d = \frac{1}{R_{tot}} = \frac{1}{R_a} + \frac{1}{R_b} + \frac{1}{R_c} \tag{1}$$

Vong et al. (2010) also provide an equation for the deposition velocity of the 0.2-0.5 µm particles, with Monin-Obukhov length (L) that describes the atmospheric stability of the boundary layer, the particle diameter D_p and an empirical constant A (Eq. 2).

$$v_d = A * u * D_p * \left(1 + \left(-\frac{300}{L}\right)^{2/3}\right) \tag{2}$$

The amount of deposited material can be calculated with the Equation 3 where LAI is the leaf area index (the amount of vegetation surface area per m^2 of ground area), C is the air concentration of the pollutant and t is the time (Janhall, 2015).

$$\text{Deposited amount } [g/m^2] = LAI * v_d * C * t \tag{3}$$

2.3.3 CFD modelling of the Atmospheric Boundary Layer

Modelling the dispersion and deposition of particles using Computational Fluid Dynamics (CFD) has shown promising results (Litschke & Kuttler, 2008; Nikolova, Janssen, Vos & Berghmans, 2014). The field of CFD is a subset of computational sciences used to solve the governing equations of fluid flow (Pulliam & Zingg, 2014, chapter 1). Three physical principles are primordial in fluid dynamics:

- the conservation of mass,
- the conservation of momentum,
- the conservation of energy.

When the fluid is Newtonian and the flow incompressible, the Navier-Stokes equations can be derived, for the continuity (mass conservation), (Eq. 4) and conservation of momentum (Eq. 5) (Pulliam & Zingg, 2014, chapter 3).

$$\frac{\partial U_i}{\partial x_i} = 0 \tag{4}$$

$$\rho\left(\frac{\partial u_i}{\partial t} + u_k \frac{\partial u_i}{\partial x_k}\right) = -\frac{\partial p}{\partial x_i} + \rho f_i + \frac{\partial}{\partial x_k}\left(\mu \frac{\partial u_i}{\partial x_k}\right) \tag{5}$$

These equations can be solved in the Eulerian or Lagrangian reference frame, in integral or differential form. Turbulent flows are characteristics of the ABL.

2.4 Plant uptake mechanisms

The monitoring of plant is a common method to investigate, monitor and map the important pollutants present in the environment, to determine its quality. A bio-marker, short for a biological marker, corresponds to any biological response (bio-chemical, physiological, histological and morphological) to an environmental chemical at the below-individual level, measured inside an organism or in its products, indicating a departure from the normal status, that cannot be detected from the intact organism. A bio-indicator is an organism that gives information on the environmental conditions of its habitats, by its presence or absence and its behaviour (van Gestel & van Brummelen, 1995). For example, some plant species are known to be sensitive to ozone and exhibit visible foliar injury. O_3 enters leaves through their stomata and follows the same path as CO_2. However, as being a highly reactive molecule, its reacts with molecules in the cell walls and damage the cell (Klumpp, Ansel & Klumpp, 2004). A bio-monitor is a bio-indicator that contains information on the quantitative aspects of the quality of the environment. Lichen and grass exposure to automobile traffic is described by Klumpp et al. (2004). Monitoring lichens help to identify the traffic-related pollutants, assessing the present impact of traffic-related pollutants on the vegetation. Finally, ecological indicators are parameters describing the structure and functioning of ecosystems (e.g. population dynamics, species diversity) (van Gestel & van Brummelen, 1995). Bio-indicators and bio-monitors give information on the degree of pollution or degradation of the ecosystems. There are complex eco-system interrelations with pollutants. When a pollutant affects an organism, they interact closely with the other ecosystem compartments. The interactions are also influenced by abiotic (e.g. temperature, precipitation) and biotic factors. By way of example, the fixation of Pb may be enhanced with aphids sticky secretions (Markert et al., 2003).

There are several possible pathways by which organisms take up elements/compounds. The bio-magnification is the absorption of the substances from the nutrients via the epithelia of the intestines, it is a major pathway for heterotrophic organisms. Bio-concentration is the term used for the direct uptake of the substances concerned from the surrounding media, through tissues, organs. It is the only pathway for plants, mainly through roots and leaves. The uptake is a species specific phenomenon. The age of the plant, its development stage are also important variables to be considered, the plant may be more vulnerable to high pollutant concentration during its growth. In addition, the degree, duration and variation of atmospheric pollution affects significantly the pollutant concentration in plants (Markert et al., 2003).

2.5 Risks for human health via dietary exposure

Heavy metals can accumulate in the plants, from contaminated soils via plant roots and with the direct deposition of contaminants via the atmosphere leading to a potential risk of contamination via consumption of polluted foodstuffs. For most people, dietary intake of heavy metals is the main pathway of exposure but inhalation can also be important (Zhuang, McBride, Xia, Li & Li, 2009). The focus here is on the risk via food ingestion. The variability in heavy metals uptake varies greatly among plant species. It is also dependent on the geochemical properties and hydrological conditions of the soil. The tolerable daily intake (TDI) is the amount of an agent (in air, food or drinking water), expressed on a body weight basis, that can be taken daily over the lifetime without appreciable health risk (World Health Organization, n.d.). For children, the intake on body weight basis is generally higher compared to adults. For Cd, Pb, organic and inorganic Hg, the TDI for oral exposure are respectively 0.5 µg/kg bw/day, 3.6 µg/kg bw/day, 0.1 µg/kg bw/day and 2 µg/kg bw/day (de Winter-Sorkina, Bakker, van Donkersgoed & van Klaveren, 2003). It is highly unlikely to reach this level of lead accumulation in human organisms. The estimated daily intake (EDI) is function of the heavy metal concentration in plants (C_{metal} in µg/g on the fresh weight basis), the daily average consumption on crops ($D_{\text{food intake}}$) and the average body weight ($B_{\text{average weight}}$) (Eq. 6)(Singh, Sharma, Agrawal & Marshall, 2010; Zhuang et al., 2009).

$$\text{EDI} = \frac{C_{\text{metal}} * D_{\text{food intake}}}{B_{\text{average weight}}} \tag{6}$$

The exposure of a population to Cd, Pb, Cu can be estimated and then compared to the TDI to assess the risk. It is also possible to reverse the Equation 6 and retrieve the maximum daily amount of food $D_{\text{food intake}}$ that can be ingested in order to avoid exceedances of the TDI (Eq. 7).

$$D_{\text{food intake}} = \frac{\text{TDI} * B_{\text{average weight}}}{C_{\text{metal}}} \tag{7}$$

As the human dietary is a combination of different foodstuffs, the human dietary intake of contaminants is usually estimated combining different data on concentrations of contaminants in different food products. In the Netherlands, the Dutch National Food Consumption Survey (DNFCS) was carried out from 2007 to 2010, depicting the consumption patterns of the Dutch population. Based on the results, the TDIs are not exceeded for the adult population. For the 2.5% of the Dutch children (1-6 years old), the TDI is exceeded for cadmium (de Winter-Sorkina et al., 2003).

2.6 Policies

2.6.1 Governance of Urban Agriculture

UA has taken a new lease of life (1.1), the concept of UA was expanded, with new purposes. It is linked to an overall popularity that can be sometimes detrimental, for its implementation, development and governance. Prové et al. (n.d.) explain the difficulty of UA governance and criticise the generic and universal directives to advance UA. They emphasise the importance of city-specific needs, opportunities and pitfalls context. Three main contextual characteristics were individualised to help the governance dynamics: the "urban layout", with the geography, socio-history of a city; the "political climate" that enframes the UA policies and strategies; the "perceptions and attitudes toward the use of urban space". A true understanding of the context in which UA emerges is the key for a good governance. UA stakeholders play a major role in its development. UA stakeholders are the individuals involved and influencing UA initiatives. It includes public officers, local administrations, supporting institutions, volunteers, pioneers, activists, farmers, social workers, educators, students, NGOs, and academics (Prové et al., n.d.). During their study, they found large disparities in the participation of the municipal government in the support of UA initiatives. Health risks in relation to UA are known: the inappropriate use of agrochemicals, crop selection or location in a polluted situation (ambient air, soil or water), livestock production and gas release, poor handling and use of waste products for compost. However, in most countries, the least-risk farming strategies to avoid negative health effect is lacking (Bakker et al., 2000, Thematic Paper 4).

2.6.2 Exposure to contaminants and thresholds

In 1960, the FAO first Regional Conference for Europe raised the desire for food standards to protect public health, facilitate trades and integrate more easily and rapidly the European market. The Codex Alimentarius was launched in 1963, aiming at facing the food safety issues, due to bio-technology, pesticides, additives and contaminants. They act as standards for international trades and are often also adopted as national guidelines (Joint FAO/WHO, 1995). Sampling plans are well defined for each contaminant and also for different food products. Different practices are also given in order to prevent or reduce the contamination, concerning different processes of the food chain, from the food production to the distribution. First, the environment must be well suited to agriculture, avoiding contamination at the source. Moreover, the following steps need also a crucial consideration: the food production processes, manufacture, processing, preparation, treatment, packing, packaging, transport and holding. Finally, if contamination happened and if the food can possibly be decontaminated, then measures can be taken in order to do so.

The European Commission set up maximum concentrations for certain contaminants in food stuffs (Council of European Union, 2006). In general, the limitations are given for nitrate, mycotoxins, metals (lead, cadmium, mercury, tin), 3-monochloropropane-1,2-diol (3-MCPD), dioxins and PCBs and PAHs (e.g. BaP).

The Government of the Netherlands requires each company to have a food safety plan and respect the food safety regulations (Government of the Netherlands, 2017). The EU General Food Law was also implemented in Dutch laws. For the international trade, the Codex Alimentarius is respected as well as the European Food Safety Authority (EFSA), an institute of research funded by the EU to assess the risk and communicate the food safety issues. Concerning the transport and sale of food, regulations are given by the Netherlands Food and Consumer Product Safety Authority (NVWA).

3 Methods

3.1 State of the art

The literature review was done using Google Scholar, Scopus, Web of Science, and Beast, EPFL's public library. The access to the library resources was provided thanks to Wageningen University & Research. Specific terms were used such as "air pollution on urban agriculture" but also using synonyms "urban farming" or by being more precise "urban communities". Some criteria were taken into account for the literature selection. They were related and relevant for the topic, scientific and also being peer-reviewed. I selected the most recent ones, in order to have up dates, in case of discrepancies (such as the sources and sinks of methane, section 2.2.1).

3.2 Interviews

Semi-structured interviews were conducted in the principal cities of the Netherlands (Amsterdam, Rotterdam, The Hague, Groningen). Jan Eelco Jansma put me in direct contact with most of the respondents, they were all working for the municipality. Mainly four topics were discussed during the interview, spatial planning; regulations and limits; food security and citizens and consumers' concern (more details are provided in Appendix B). If precise questions were defined, the interviews were kept in an informal and pleasant atmosphere, following the flow of the conversation. The length of the interviews was about one hour. They were not recorded, but I took some notes and directly transcribed them right after each interview to not to loose information.

3.3 Bio-monitoring and modelling

3.3.1 Bio-monitoring

The protocol was the same as the one implemented by van Dijk et al. (2015) in the long term bio-monitoring in the vicinity of waste incinerators. Three sites were monitored in Amsterdam (Map 1), two were within the municipality of Amsterdam whereas the third was in the metropolitan region of Amsterdam near Schiphol airport. A blank test was also proceeded in Wageningen, as a rural site representing background levels. The experiments were renewed three times. Each sampling location was first provided with an anti-rooting plastic to suppress weed growth and prevent contamination of the plants with soil particulates from the immediate vicinity. In Wageningen, the location was in an open field. Therefore, a 1 m high fence and windscreen was set up to protect the plants against rabbit/hare herbivory and wind damage. Two different spinach species were used, the first one is a winter-early spring species (Dolphin) and reaches its mature age in about 50 to 60 days (8 weeks on the field). The second specie (Tiger) is mature at about 30 days (4 weeks), during the spring. Spinach is used as an accumulator crop because it has a high growth rate, large leaf area and growing season. Plants were cultivated in 50 dm^3 containers with standard soil ('Lentse' soil No. 3, Horticoop, Bleiswijk, NL) with an automatic water supply consisting of a container of water (tap-water) underneath the soil container. Ropes go from one container to the other, keeping the soil moist by capillarity. This technique was adopted from Posthumus in 1982. Per sampling sites, all leaf material was harvested, mixed and dried at 40°°C for 48 h and then grounded to 1 mm. The following pollutants were measured: heavy metals (Cd, Cu, Hg, Pb), nitrate, PAHs (16 EPA). They were selected because they are present as gas in the air, or being transported by particulate matters in the air (refer to the section 2.2.2). They are also relevant in terms of plant uptake (2.2.3). Cadmium, copper and lead are related to traffic, copper especially is related to brake wear. Lead was present in gasoline but it has been removed and is now less prominent. Nitrate is related to both traffic and agriculture practices i.e. the use of fertilisers. Finally, PAHs are emitted anthropologically by incinerators, industrial processes, automobile emissions, BBQ, etc. Cadmium, copper, mercury and PAHs were bio-monitored on a 10-years period study conducted by van Dijk et al. (2015) in the Netherlands. Therefore, mercury was additionally measured as it was interesting to compare both our results in Amsterdam with the previous 10 years background data.

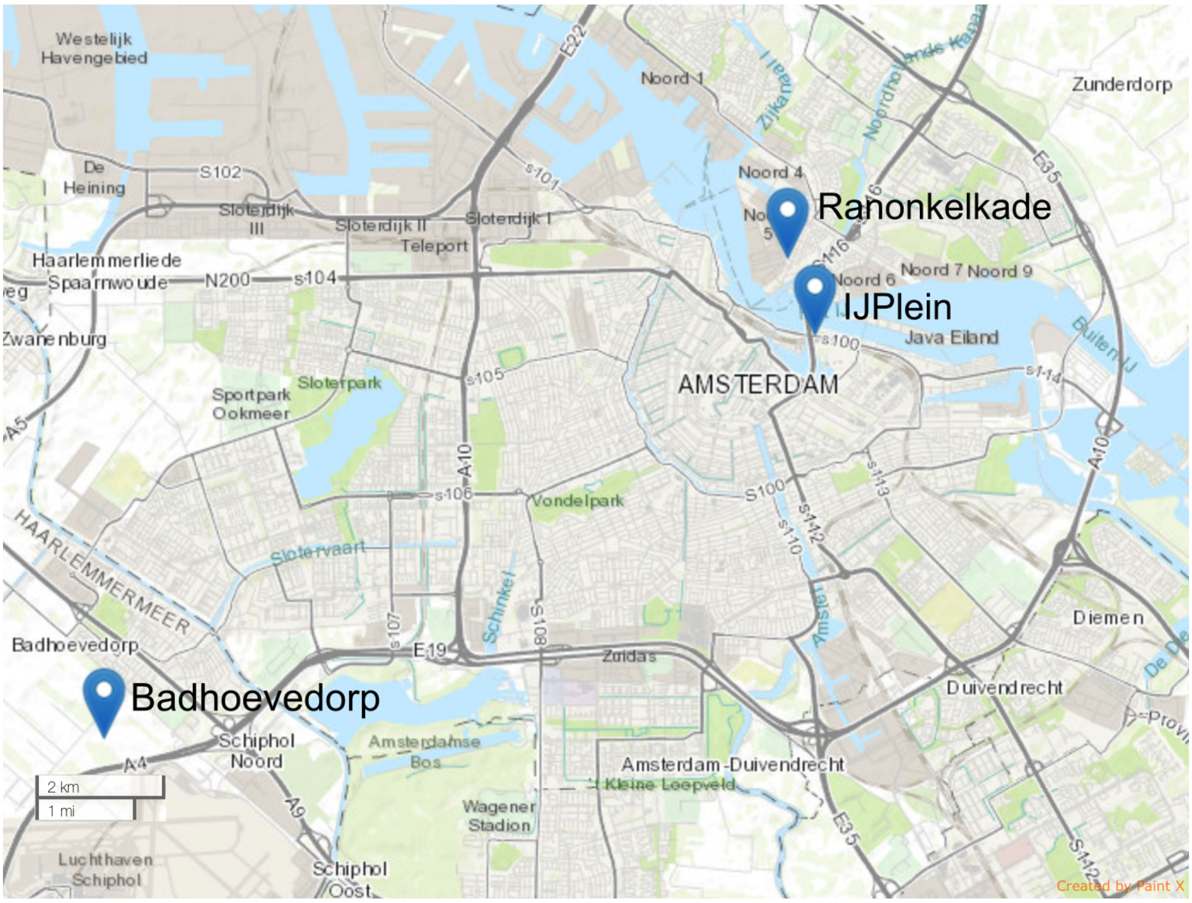


Figure 1 – Map of the sampling sites in Amsterdam (National Geographic, 2017)

The Voedseltuinen IJplein community garden (photos 12a, 12b) is just across the IJ, northern Amsterdam. It is a large area (of about 2500 m^2), without any surrounding trees. Although the dyke protects the garden from the IJ, it remains a very windy place. The IJtunnel passes closely to/underneath the garden. The photo 12a shows only a small part of the garden. The photo 12b is a view of the garden from the top, there is a range of three buildings west to the garden, of about 30 m high. The red spot corresponds to the location of the containers. It is also close to another building, lower in size. Secondly, Ranonkelkade is a small private garden (no public access) in a residential area in Amsterdam Noord (photos 13a, 13b). This garden belongs to Eetbar Amsterdam community. There are no big industries in the surroundings, nor busy roads. The last location is on a private allotment, of Suzanne Oommen, in Vrienden van Sloterland (photo 14a, 14b). It is situated southern Amsterdam in Badhoevedorp, in the peri urban zone of Amsterdam, close to Schiphol airport and in between the A4 and A9 motorways. It is a highly diversified garden, where individuals have their own allotment and grow food for their own consumption.

The background concentrations were also retrieved with the results of the long term bio-monitoring of van Dijk et al. (2015). Descriptive statistics such as the median, the interquartile range (IQR), minimum and maximum concentrations of three rural sites (Alkmaar, Harlingen, Wijster) were calculated over a ten years period (2006-2016) for the heavy metals cadmium and mercury and for the 16 EPA PAHs.

The results were also compared to the limits given by the Codex Alimentarius and the European Commission, that must be respected if one wants to commercialise its products respectively on the international or European market.

The health risk associated with heavy metals was estimated with the EDI (2.5). The maximum daily ingested amount of spinach to not to exceed the TDI was calculated for some heavy metals (Cd, Hg, Pb) with the Equation 7.

3.3.2 Modelling

In order to complement the bio-monitoring and understand better its results, the modelling of Amsterdam's environment (meteorology, air quality) and the pollutants dispersion and deposition were assessed. The statistical environment R was used to retrieve statistics on the first part. Subsequently, Ansys Fluent, a CFD model was employed to draw a specific environment and simulates the air pollutants' dispersion and deposition.

- Environment characteristics of the city of Amsterdam - R

  Amsterdam has a population of about 847,000. It has no heavy industry in the surrounding but the national Schiphol airport is located 10 km west of the city. One problematic issue in terms of air quality is the three dense main traffic axis surrounding Amsterdam.

  Meteorological data were analysed in order to complement the results of the bio-monitoring and also to give right inputs to the CFD simulations. The data were extracted from the KNMI website. The meteorological data are real-time data. There are only a few stations within the Netherlands. Schiphol station was associated to Amsterdam, Deelen to a countryside reference. Rotterdam was also added to the study in order to have an additional urban station.

  In parallel, data on air pollutants in Amsterdam was downloaded from the air quality monitoring network Lucht Meet Net. There are about 10 air quality monitoring stations in and around Amsterdam. Three of them were selected (Badhoevedorp, Nieuwendammerdijk and Van Diemenstraat stations), in the vicinity and representative of the experimental sites. The measuring station Badhoevedorp is considered to be an urban background station, with few people living in the surroundings, the vicinity of Schiphol Airport and busy roads. A junction connecting the A4 motorway to the A9 was opened in June 2016. Van Diemenstraat is classified as a street station. High road traffic emissions are related to the inner city 1 lane road. Finally, the Nieuwendammerdijk measuring station is considered as an urban background station, it is located in a residential area, where there is no busy roads, ports and industries close by. The files were opened and analysed with R for spring 2016. Indeed, the data are not continuous over time and as they need to be validated before being inserted on the website, the 2017 data were unfortunately not available. Some statistics were then drawn up on air pollutants (PM_{10}, CO, etc).

- Dispersion & deposition modelling - Ansys Fluent v18.0

  Two cases were designed with Ansys Fluent CFD model: an urban area (Fig. 2), with urban background concentrations, traffic emissions (corresponding to the neighbourhood of Ranonkelkade location) and a rural area, with background concentrations only (corresponding to Wageningen station, Fig. 3).

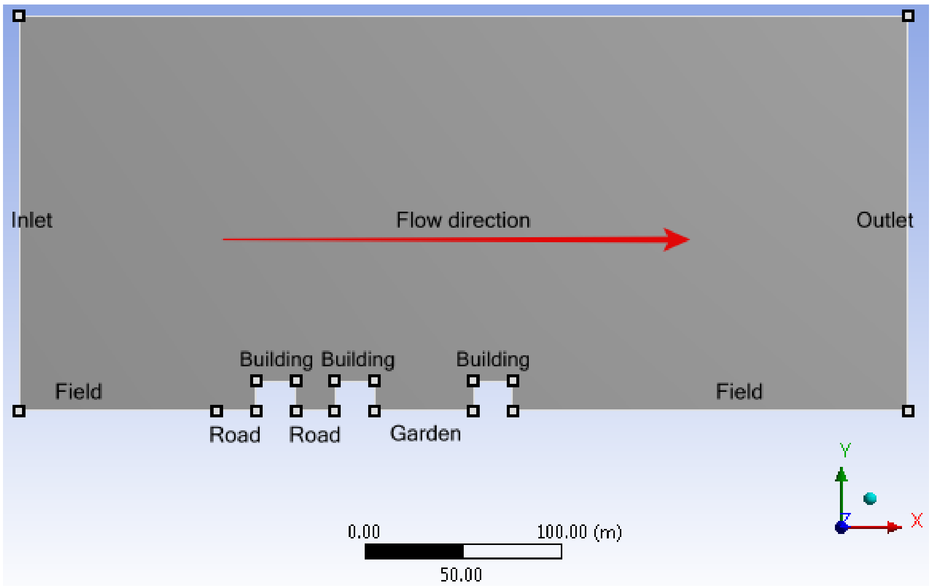


Figure 2 – Design of the urban environment (ANSYS Inc, 2016)

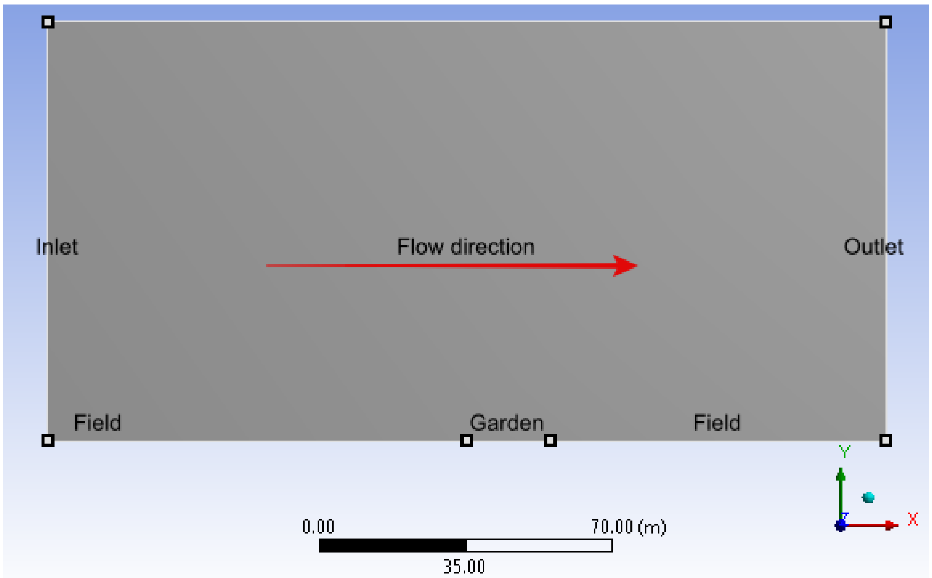


Figure 3 – Design of the rural environment (ANSYS Inc, 2016)

The air in the two models is assumed to be an incompressible turbulent flow. Timeaveraged Navier-Stokes equations (RANS) decompose the fluctuating variables of a turbulent flow into a mean and fluctuating term. Several RANS models are implemented in Ansys Fluent and the two equations, steady-state standard k-ε model was chosen for its robustness and efficiency (Franke et al., 2004; Thaker & Gokhale, 2016). It is the most widely used turbulence model in industrial CFD (Franke et al., 2004; Hargreaves & Wright, 2007) and it has shown optimal results for pollutant dispersion related to different urban geometries (Sabatino, Buccolieri, Pulvirenti & Britter, 2008). Large eddy simulation (LES) turbulent models also provide accurate solutions but they require a higher central processing unit (CPU) time (Franke et al., 2004).

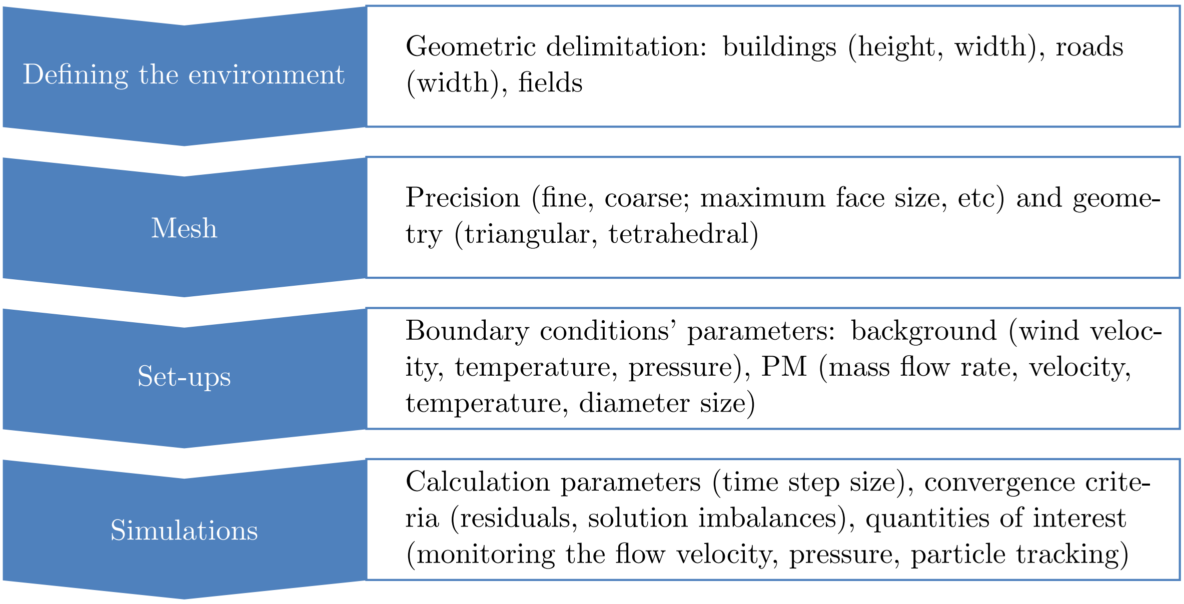


Figure 4 – CFD model routine

Figure 4 gives the sequence of actions that had been followed while using Ansys Fluent. Each step of the routine is further described below. The choices of parameters for each step were made using Ansys Fluent manual (ANSYS Inc, 2016), the forum cfd-online.com and scientific literature.

1. First, the geometric environment was defined. The guidelines of Hall (Franke et al., 2004) were applied for the urban environment: the inlet and top boundary were at least 5H away from the buildings, H being the height of the building. It was set at 15 m looking roughly at Ranonkelkade's neighbourhood on Google Maps. The distance from the buildings to the outflow boundary was long enough to ensure a full development of the flow (200 m, more than 13H).

2. Then, the grid for which the Navier-Stokes equations were solved (at each node) was specified. The maximum size between two nodes was set to 1.0 m. It is an important step as it defines the spatial resolution of the numerical solution (Franke et al., 2004).

3. Furthermore, the boundary conditions allowed to better describe the environment. The inlet (left surface) was a velocity inlet, set to 4 m/s with respect to the previous results of the meteorological data for Amsterdam and Wageningen. The outlet was defined as a pressure outlet. The sky boundary was considered as a symmetry plane,

meaning that the flux at this boundary is mirrored back into the domain. It is a frequent convention accepted for top boundaries as well as for lateral boundaries, except if the CFD practitioner needs to set outflow parameters (e.g. flow velocity) (Franke et al., 2004). No slip conditions were applied to the walls. The temperature of the interior was given using the results of the previous statistics: the simulations were based on Amsterdam's average for the month of June (288.16 K). However, the temperature was also changed to March and April's averages in order to see the possible effects on the flow and pollutant deposition.

The canopy is a complex structure that can be incorporated with the roughness parametrisation (Maurer, Bohrer, Kenny & Ivanov, 2015). In Ansys Fluent, it is described by two parameters: the constant C_s and the roughness height K_s (ANSYS Inc, 2016). The roughness of the walls and roads were set to default values while for the gardens C_s was maximised (value of 1) and K_s was set to 0.3. These parameters can lead to high discrepancies between CFD simulations and measurements (Hargreaves & Wright, 2007). Some basic requirements are given by ANSYS Inc (2016) for an accurate ABL flow simulation near the ground surface:

(a) A sufficient high vertical resolution of the vertical mesh (e.g. height of the first cell < 1 m).

(b) A horizontally homogeneous ABL flow in the upstream and downstream region of the domain.

(c) A distance y_p from the centre point P of the adjacent wall that is larger than the physical roughness height K_s of the terrain ($y_p > K_s$) (Blocken, Stathopoulos & Carmeliet, 2007). In the two configurations, y_p is about 0.5 m as the maximum face size is 1 m.

Blocken et al. (2007) provide guidelines to choose the right parameters (Eq. 8). y_0 is the aerodynamic roughness length, it was set to 0.06 (agricultural land) (Steyaert & Knox, 2008). K_s can then be retrieved with the Equation 8 (0.3). In order to satisfy $y_p > K_s$, C_s was maximised to 1.

$$K_s = \frac{9.793 * y_0}{C_s} \tag{8}$$

Emissions from the left-inlet (corresponding to the background air pollution) and roads (car exhaust emission) were simulated. In the discrete phase model (DPM), the particles are tracked inside the continuous phase (air) using particles tracking method in Lagrangian Frame (ANSYS Inc, 2016). The background particles were given as inert particles (assuming the properties of ash), with a diameter of 10 µm, a temperature of 288.16 K (as the global surrounding temperature) and a mass flow rate of 1.0E-03 kg/s. Ash is one of the pre-defined inert particles on Ansys Fluent (default is anthracite). Ash PM is also emitted by diesel engines (Liati, Spiteri, Dimopoulos Eggenschwiler & Vogel-Schäuble, 2012). To ease the modelling, chemical transformations were not set as the simulations were run with a timescale of seconds to minutes. PM_{10} are relevant components in terms of air pollutants, as they contain heavy metals, and their dry deposition occurs mainly via gravitational settling (sections 2.2.2 and 2.3.2). The order of the mass flow rate was fixed superficially using the Equation 9. In literature, the range of mass flow rate varies highly. The choice of the value was based on studies related to road emissions (Ruellan & Cachier, 2001; Sabatino et al., 2008). However, as the model was tracking inert particles, it was important to look at the amount of particles deposited in relation to the mass flow rate and flow time. The same mass flow rate was used for the rural and urban environment to observe the impact of the design on the deposited amount.

$$\dot{m} = \frac{V * C}{t} \tag{9}$$

Where:
$\dot{m}$ = Mass flow rate [kg/s]
V = Volume of the domain [m^3], for the urban design, 450 m x 200 m x 1m = 90,000 m^3
C = Average concentration [μg/m^3], for PM_{10} in Amsterdam, 20 μg/m^3, section 4.3.2
t = Time [1 s]

The car exhaust was also set as an inert particle (assuming the properties of ash), with a diameter of 1 μm, a mass flow rate of 1.0E-03 kg/s (assuming an equal contribution of both sources) and a temperature of 480 K (using Huang et al. (2014) parametrisation for CFD modelling of particle emissions near highways). Most of the particles emitted from car exhausts are smaller than PM_{10} (Huang et al., 2014; Tong et al., 2012; Uhrner et al., 2007). For this reason, $PM_{2.5}$ and UFP were considered, and the particle diameter was swept from 1 μm to 2.5 μm. The Brownian motion was accordingly allowed as it is of an increasing importance with the decrease of the particle size (section 2.3.2). The velocity of the background and traffic emission particles was set to null so that they would be carried by the flow. The particles can escape from the inlet and the outlet. They can be trapped by the gardens and the buildings and fields were set to reflect them.

4. The flow was solved with transient simulations (because of unsteady features e.g. vortices) and the gravity was set to -9.806 m/s^2 on the Y-axis (ANSYS Inc, 2016). The simulations were run and the results analysed in order to modify, adjust the parameters. For the two environments, the flow was simulated for a long time, longer than just the time needed for the particles to cross the whole domain, with the intention of lowering residuals and reaching a global equilibrium of the system. If in industrial applications a terminal criterion of 10^{-3} is used for the residuals, Franke, Hellsten, Schlünzen and Carissimo (2007) suggest having at least four orders of magnitude. Smaller time steps, as well as a very fine mesh, lead to definite convergence but it requires a lot of time. Therefore, one has to make trade-offs between convergence criterion and CPU time (Franke et al., 2007). I decided to accept the results once the residuals were below 10^{-4} for the final results, and tolerated residuals below 10^{-3} when sweeping the input parameters. The time step size was swept several times (0.1, 0.05, 0.01 s) and I opted for 0.01 s for the final results. The mass imbalance is another means for assessing CFD convergence. Once the residuals were acceptable, the first step was to look at the flow pattern in the environment, whether it fits with the expectancies in terms of turbulence, flow velocity, pressure. Then, concerning the particle tracking, some graph were

retrieved: the Y-velocity of the particles and its concentration in the garden. These values were further compared to the literature.

Table 1 – Geometric characteristics of the urban domain

Geometry	
Height of the domain	200 m
Length of the domain	450 m
Max Face Size	1.0 m
Total number of elements	89,100
Total number of nodes	89,796

Table 2 – Boundary conditions of the urban domain

Boundary	Boundary conditions
Air inlet	Velocity (normal to boundary) = 4 m/s T = 288.16 K
	DPM as inert particle Mass flow rate = 1.0E-03 kg/s Particle diameter: d_p = 10 µm T = 288.16 K
Outlet	Pressure outlet
Roads	Velocity (normal to boundary) = 0.1 m/s
	DPM as inert particle Mass flow rate = 1.0E-03 kg/s Particle diameter: d_p = 1 µm T = 480 K
Gardens	$C_s = 1$ $K_s = 0.3$
Wall	No slip boundary conditions
Top (geostrophic wind)	Symmetry

For the urban site, the characteristics of the geometry, grid and boundary conditions are reported in Tables 1, 2. Figure 2 represents the design of the domain. The discretised domain had 89,100 elements and 89,796 nodes. As the background wind velocity is 4 m/s, and the length of the domain 450 m, 112.5 s are needed for the wind to cross the whole domain, corresponding to 2,250 time steps with a time step size of 0.05 s.

For the rural site, the characteristics are given in Tables 7 and 8, in Appendix D. The domain is small compared to the urban site (Fig. 3) as the effect of the buildings required a greater height due to induced turbulence. Therefore, the discretised domain had 20,000 elements and 20,301 nodes. Compared to the rural site, only the buildings and road emissions were taken off. The inlet, outlet, wall functions and roughness parameters remain the same. 50 s are needed for the flow to travel through the domain (200 m length).

4 Results

4.1 State of the art

Defining all the terms, from UA to air pollutants and their deposition on plants, etc, helped to understand the current status of UA with respect to its peculiar environment. Few studies have been focusing on the specific risk of air pollution on UA.

Säumel et al. (2012) were the first, to my knowledge, to discuss about the impact of traffic on UA. They collected samples, grown in the soil bed of community gardens in the inner city of Berlin and analysed them in order to trace metal accumulation (Cd, Cr, Cu, Pb, Ni and Zn). Their main results can be summarised as follow:

- Metals concentration differs a lot among plant species. However, the concentration is not significantly affected by the type of vegetable (i.e. fruit, stem or leaf vegetables). Not all leaf vegetables observed higher Cr, Cu, Ni or Zn levels.
- The mode of cultivation (raised beds vs. soil) is an additional factor that may explain the dissimilarity of the results.
- The adjacent environment (urban traffic, the presence of vegetation or buildings that can act as a barrier) plays an important role allowing to trace metal concentration. For example, in the vicinity of roads, crops had higher lead contents.
- The metal content was higher in urban crop samples than in samples from the supermarket. They were comparable to levels observed by vegetables grown in the vicinity of smelters or irrigated by waste water.
- The Cd levels were almost all under the legal limit given by the European Union for the concentration in food crops. Nevertheless, Pb concentrations exceeded the European Union standards for Pb in food crops for 52% of all samples.

Säumel et al. (2012) have been quite popular (cited 72 times, 21 July 2017) and since their first publication, many studies further deepened the impact of air pollution, mostly from traffic and industrial emissions on UA (Amato-Lourenco et al., 2017; H.-S. Kim, Kim, Lim, Kim & Kim, 2015). Amato-Lourenco et al. (2017) demonstrated an enrichment of several elements of the urban gardens in relation to the traffic, in São Paulo, Brazil. The roses were grown in flowerbeds with uncontaminated and standardised soil. In a similar manner as Säumel et al. (2012), they indicated the negative association between the traffic distance, vertical obstacles and the micro nuclei frequency of *Tradescantia pallida* (rose), being an indicator for the cytogenetic damage to cells. H.-S. Kim et al. (2015) monitored crops grown in identical media and compost, from rooftops in Seoul, Korea. They observed similar concentrations in their plants compared to natural levels. They also mentioned the importance of washing the vegetables as they observed a corresponding reduction of the hazard quotient by 17-28%. If all the concentrations were below the standard limits (Korean Food Standard Codex), Cu and Zn had elevated levels. A more recent study focused on the heavy metals accumulations in vegetables grown in urban gardens, in Bologna, Italy (Antisari et al., 2015). They observed the increased risk of heavy metals accumulation in the proximity of pollution sources, mainly traffic. Like Amato-Lourenco et al. (2017), they noticed the road distance and traces of heavy metals dependency. However, the overall urban pollutant accumulation achieved similar levels as in the rural areas. In conclusion, Antisari et al. (2015) tackled the importance of the spatial planning (e.g. allotments at a reasonable distance from roads, the presence of natural barriers, assessment of the soil quality).

4.2 Interviews

4.2.1 Amsterdam

In Amsterdam, I had the opportunity to meet Frank Bakkum, a geographer of the city of Amsterdam. He is currently working on a website that registers all food chain initiatives, from the recycling to the marketing of the vegetables (vanamsterdamsebodem.nl). The platform was launched the 28 February 2017 in order to stimulate these initiatives, to connect them and to make them more visible. UA is a topic *en vogue*, with multiple positive aspects that the city wants to encourage. The city of Amsterdam actually provides subsidies to the new initiatives. Among the points raised during the discussion, the regulations and limits in terms of pollutant concentrations within the food were considered. A distinction was made between the regular consumers of urban gardens' products and the self-sufficient citizens, the latter being subjected to higher risks due to a diet based on the only consumption of urban harvests. The municipality of Amsterdam is aware of the possible risk of ingesting pollutants when consuming food grown in the city but also realises that it is related to great amounts of food ingested. If the soil pollution remains the main popular issue, air pollution begins to be of interest. Recently, the municipality of Amsterdam has been focusing on the air pollution and flow in and around the city. Indeed, the city structure is known to have an impact on the circulation of the pollutants and designing the city taking into account these aspects gains popularity.

4.2.2 The Hague

Tom Voorma works for the municipality of The Hague on the digital mapping of the UA initiatives (stadslandbouwdenhaag.nl). In comparison to Amsterdam's website, it has the same goal of merging initiatives but focusing more on UA. The website targets principally the researchers, but also housing corporations, etc. It is a good way to make the municipality understand why they should support these initiatives. It is also a means to make people aware of how the world can benefit from that insight. It gives directives to create an UA initiative, answering questions such as how to raise funds, how to create a social spot. UA is not strictly defined, initiatives in the edges of The Hague are also included, "there are no strict boundaries, UA is in and around the city". A typical initiative is made of a core of three-four persons, with about fifteen additional people quite involved that support the initiative. After that, there is a wide range of participants, from 50 to 200 that occasionally help a few times a year. The communities also have their own social habits, with dinner reunions, sharing the products, educational activities for children, etc. In The Hague, the production of UA is quite limited, the gardens are not big enough to provide further vegetables for the markets. However, few of them are relatively large "of the size of a soccer field". Another initiative is currently working on setting up a garden in collaboration with a restaurant. The Hague is not considered to be very polluted as there are no industries, nor heavy traffic. However, in the inner city, some questions are raised about the health security, in connection to UA: for instance, when walking with pets, the proximity to public toilets, or with the garden being right next to a highly used road. Indeed, if citizens are relatively aware of the risk in the Hague, these risks mainly concern soil pollution and not health security.

4.2.3 Groningen

Anke van Duuren works in the municipality of Groningen, she collaborates with many companies/restaurants to improve the health of the citizens, implementing the "Dutch cuisine" concept. It aims at having more sustainable food, healthier and tastier. For example, alternative non-traditional animal proteins are proposed in restaurants, like buckwheat, seaweed, etc. They also realised a series, GoudGroen, composed of 10 short episodes, on OOG local television. The first episode is about greening your garden, as a solution to the impermeability of the urban soil and the water run off. Regarding the UA initiatives, there are about 60 gardens in the municipality of Groningen. They are registered on the website eetbarestadgroningen.nl. As for Amsterdam and The Hague, the municipality helps the initiatives to launch their own project, giving them directives, money and mostly materials. All the soils are subjected to tests in order to assess their pollution level. If one soil is too polluted then the project can be refused, or the soil can be cleaned up. When an urban farming project is created and supervised by the municipality, it is not linked to the air quality around its location. There is an air pollution section at the municipality but they do not collaborate. Besides, the air around Groningen is clean enough as they do not have any industries around. Therefore, the citizens do not feel concerned by this issue either. One of their projects is 'Toentje'. It was created in collaboration with the Food Bank to alleviate poverty through food production, education and health promotion. The municipality is also active in informing the citizens on how to be more sustainable.

4.3 Bio-monitoring and modelling

4.3.1 Bio-monitoring

Spinach was monitored over a three-month period. Spinach was first sown in Wageningen and then implemented in Amsterdam when the green leaves were sprouting (after 7 to 10 days). The first experiment was on the field for 8 weeks, from the 28th of March to the 9th of May 2017. For the second and third experiments, a different cultivar was used, requiring only 4 weeks in the field. They were implemented in Amsterdam from the 9th of May to the 6th of June and from the 6th of June to the 11th of July 2017, respectively. The third batch died because of elevated temperatures and the seeds were sown again, right before going to Amsterdam the 6th of June. Table 3 describes the weather condition in Amsterdam during the three periods. The descriptive statistics were retrieved from the KNMI website. The first period was marked by regular temperatures and humidity (section 4.3.2) for a spring in the Netherlands, the growth conditions were good for the spinach, not requiring additional water. The second experiment was especially subjected to high - unusual temperatures and had to be additionally watered to avoid drought stress and losses. The beginning of the third period was also characterised by warm temperatures, spinach was watered once. Additional water was added to the containers below but also directly to the soil, carefully avoiding watering from above that would cause water to run off the leaves (with the potential deposited pollutants). In Wageningen, at Ranonkelkade and Badhoevedorp locations, the crops were watered with tap water. At the IJPlein garden, rain water was used.

Table 3 – Summary of the weather conditions for each period in Amsterdam. The data were retrieved from the KNMI website for Schipol station. The temperature is the average of the daily mean temperature. Its standard deviation is also given in parenthesis to observe the variability of the weather.

	Period 1	Period 2	Period 3
Average temperature [°C]	9.6 (2.2)	16.3 (3.3)	18.1 (2.1)
Precipitation amount [mm]	37.6	38.1	81.2

The concentrations of the heavy metals (Cd, Cu, Hg, Pb), nitrate and PAHs (16 EPA) are given in Tables 9 and 10, for the three periods. Figures 15a, 15b, 15c and 15d (Appendix E) present to the concentrations observed for the heavy metals with the rural background values calculated with the long-term bio-monitoring results from van Dijk et al. (2015). Similarly, Figures 16a, 16b, 16c, 16d, 16e and 16f give the results for the 16 EPA PAHs. First, the results are described for each component individually, then a general summary is given.

1. Heavy metals

   The multiple period results from the bio-monitoring programs in this study showed that individual Cd levels in spinach exhibited some variations mostly throughout the season rather than per sampling points, including the reference point (Wageningen). The first period had Cd levels under the rural background median value. The second period showed concentrations above the rural background median, still in the IQR. The last period experienced levels in between, close to the rural background median value (Fig. 15a). The order of magnitude of the Cd levels was similar for the four locations, below the 0.20 mg/kg fresh weight limit as given in the Codex Alimentarius and by the European Commission (Table 11).

   The levels of Cu were generally higher for the first period (Fig. 15b). The highest concentrations were found at the IJPlein, for each period, and the lowest was observed in Wageningen. If the concentrations followed the same patterns (higher concentrations for the first period, slightly lower for the second, greater decrease for the last period) in Badhoevedorp, Ranonkelkade and Wageningen, at the IJPlein the concentration was at its highest for the third period. Yet, no background concentrations were defined as Cu was not measured during the long term bio-monitoring by van Dijk et al. (2015).

   Concerning Hg, the levels were low throughout the whole bio-monitoring period (Table 4). As observed for Cd, the concentrations were mostly in the IQR or below the first quartile (Fig. 15d). One exception is for the first period in Badhoevedorp where the IQR was slightly exceeded by 0.23 μg/kg f.w. (the standard deviation of the results of the first period is 0.13 μg/kg, Table 4). In general, the concentrations were slightly higher for the first period and the second and third periods had very similar concentrations. No maximum acceptable Hg level for leaf vegetables have been defined.

   Regarding Pb, the levels were similar for the three periods for each site. Ranonkelkade location exhibited stronger variations than the other sites in between the periods: for the first sampling, the concentration was almost twice as high as the ones of the other locations (73 μg/kg at Ranonkelkade vs 26 μg/kg at Badhoevedorp) but it dropped during the second and third period. However, the concentrations remained very low, far below the legal limit. Pb was not monitored during the 10-years program, therefore no long-term rural background concentrations were added to the graph.

Altogether, for the heavy metals:

- The levels did not differ significantly in Amsterdam, in comparison with Wageningen. The heavy metals showed different trends at each site: for cadmium, the concentrations were similar for all of them; for copper, concentrations were systematically higher at Badhoevedorp; for lead, Ranonkelkade experienced much stronger variations; for lead, levels were globally similar, slightly higher at the IJPlein.
- Concentrations were also varying per period. It was especially visible for cadmium and mercury. The concentrations were low for the third period, for copper, lead and mercury.
- When comparing the results to the long-term bio-monitoring data, the results from this study are mostly in the IQR, therefore similar to the 10-years rural background.
- The legal limits for the commercialisation of foodstuffs, fixed for cadmium and lead, were never exceeded.

2. Nitrate

Nitrate levels increased noticeably from the first to the second period (Table 4, Fig. 5). The third period experienced the lowest concentrations, with an average of 224 mg/kg. Ranonkelkade location had the highest concentrations during the second and third periods, the lowest for the first one. Moreover, the concentration variation in between the sites was low for the first and third period, in comparison to the second period. Finally, the concentrations were always lower than the legal limit (3,500 mg/kg).

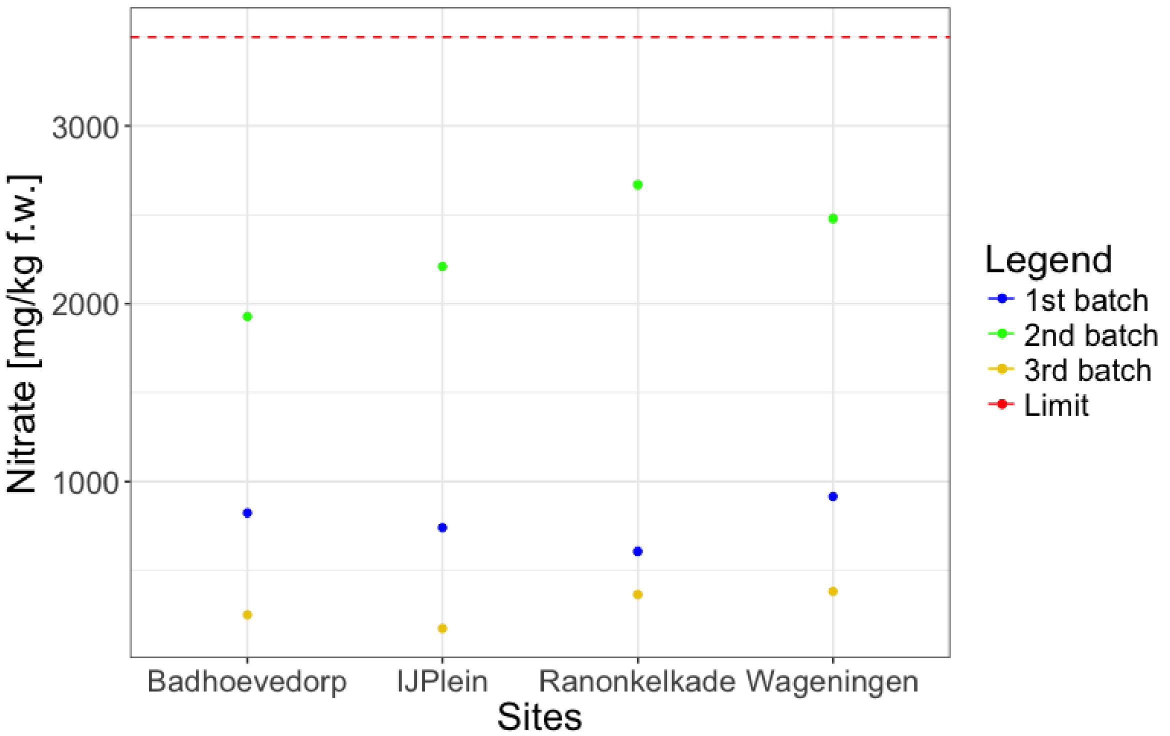


Figure 5 – Nitrate levels for the three periods, the red-dashed line corresponds to the legal limit from the European Commission for fresh spinach

3. PAHs

Variations in PAH levels also occurred throughout the season and per sampling sites. The elevated total PAH levels were the results of high levels of individual PAHs, in particular, fluoranthene and phenanthrene. The first and third periods had very similar concentrations while a global increase was observed for the second period. The third experiment had globally lower concentrations, with half of the components below the detection limit (Table 10). Looking individually at each PAH helped to interpret the status of the results: first, in relation to their different location, in Amsterdam or in rural Netherlands; then, with regard to the 10-years rural trend.

Figure 16a presents the results for benzo(a)anthracene. For the two first periods, higher values were observed in Amsterdam in comparison with Wageningen. The third period exhibited similar concentrations for all the sites. In comparison with the long-term bio-monitoring study, at Badhoevedorp, IJPlein and Ranonkelkade, the values were above the third quartile, for the two first periods. Ranonkelkade level for the first period was close to the maximum observed during the 10-years study of van Dijk et al. (2015). The concentrations were always below the first quartile for the last period, being under the detection limit. Wageningen, the rural background of the study, was the most similar to the 10-years rural background tendency, its values being mostly in the IQR, and close to the median for the two first periods especially.

In a like manner, benzo(b/j)fluoranthene concentrations were higher in Amsterdam (particularly for Ranonkelkade) compared to Wageningen, the rural background (Fig. 16b). For the third period, the concentrations for all the sites were around the rural median and generally above the third quartile for the first two periods.

Next, benzo(k)fluoranthene and benzo.a.pyrene showed similar trends: the concentrations for the two first periods varying much more than the last one. For the second and third periods, the concentrations were higher at the IJPlein and at Ranonkelkade locations, Badhoeverdorp and Wageningen, exhibiting lower and more similar values. For benzo(k)fluoranthene, the concentrations observed were in the lowest part of the (or below) IQR for the first and third period (except for Ranonkelkade, first period); above the IQR for the second period (except at Badhoevedorp). For benzo.a.pyrene, for all the locations, the levels were above the third quartile for the first and second periods, in the lowest part of the IQR queue for the third period. Still, the concentrations never exceeded the maximum concentration observed in the 10-years rural study.

For chrysene, similar patterns could be observed, the last period exhibiting lower concentrations than the two first ones for each site (Fig. 16c). Concentrations are higher in Amsterdam, especially in Ranonkelkade. Badhoevedorp had levels comparable to Wageningen. The variability of the results is higher in Amsterdam compared to the range of the three concentrations in Wageningen. Now considering the results of the long term program in rural Netherlands, the values were mostly above the IQR of the rural background concentrations for the IJPlein and Ranonkelkade. For all the periods, Wageningen had the lowest concentrations, in the IQR and below the first quartile. Badhoevedorp was similar to Wageningen, with concentrations slightly higher (especially for the first period).

Then, for dibenzo(ah)anthracene, the second and third periods had values under the detection limit (Table 10). The first period had concentrations above the detection limit, being higher at Ranonkelkade, then at Wageningen. Badhoevedorp and the IJPlein had similar concentrations. When being contrasted with the long-term bio-monitoring data, the levels were higher than the third quartile, for the first period, but still below the maximum concentration.

For fluoranthene, the results showed a higher range of concentrations for all the sites in Amsterdam, in comparison to Wageningen. However, the concentrations remained low, being always below the median and essentially below the first quartile of the long-term bio-monitoring (Fig. 16d).

Next, the results for indeno(123cd)pyrene were similar to the ones obtained for benzo(k)-fluoranthene and benzo(a)pyrene. The first and second periods had irregular patterns, with generally higher concentrations northern Amsterdam (IJPlein and Ranonkelkade). When compared to the long-term bio-monitoring program: the last period had low concentrations (below the detection limit), mostly below the first quartile and even lower than the minimum concentration for Wageningen. The other two periods presented concentrations above the third quartile.

Phenanthrene had been varying per period, rather than per site (Fig. 16e). The concentrations were low for the first and third periods, below the background rural median, based on long-term results, and above the third quartile for the second period.

To summarise the results of the PAHs concentrations of the three-month bio-monitoring:

- For benzo(a)anthracene, benzo(b/j)fluoranthene, benzo(ghi)perylene and chrysene, the concentrations were globally more variable in Amsterdam than in Wageningen. When looking at the 10-years background results, these urban sites experienced concentrations above the third quartile of the 10-year rural background study, for the first two periods especially. The last period exhibited almost always the lowest values per site, with more than half of the concentrations being under the detection limit.

- For acenaphthene, acenaphthylene, anthracene, fluoranthene, naphthalene and pyrene, no distinction was identified in between the different sites (within Amsterdam and compared to Wageningen, the rural background). The levels were systematically lower for our study compared to the median (and also to the first quartile) of the rural background.

- Globally, considering the total PAHs concentrations (Fig. 16f): for the second period, it was higher in Amsterdam compared to Wageningen. Yet, it was not the case for the first and third periods, the third one especially displaying almost no variation per site. In comparison to the results of the long term bio-monitoring in the Netherlands by van Dijk et al. (2015), the total concentrations of the 16 EPA PAHs were low compared to the median of the rural background, in the lowest part of the IQR (between the first quartile and the median) for the second period, and lower than the first quartile for the two others (Fig. 16f).

The daily maximum recommended ingested amount of spinach is given in Table 5, for a body weight of 70 kg. It was deduced using the Equation 7 and using the TDI reference values for Cd, Hg and Pb, given in 2.5. Above these values, the TDI is overwhelmed. As an illustration, one can eat a maximum daily amount of 346 mg of the spinach I grew without appreciable health risk, based on the highest concentrations observed in all the locations. The values were much lower for Cd compared to Hg and Pb where kilos of spinach should be ingested daily to reach the TDI.

Table 4 – Average and standard deviation of heavy metals and nitrate in µg/kg fresh weight (f.w.) of spinach for the three periods. Legal limits are also given for some of the pollutants.

	Week 19 - 2017	Week 23 - 2017	Week 28 - 2017	Threshold
Cd	6.59E+01 (5.69E+00)	9.66E+01 (4.60E+00)	7.90E+01 (7.77E+00)	2.0E+02
Cu	6.46E+02 (2.23E+01)	6.26E+02 (1.72E+01)	5.76E+02 (9.38E+01)	-
Hg	1.52E+00 (1.34E-01)	1.08E+00 (1.00E-01)	1.15E+00 (1.78E-01)	-
Pb	4.02E+01 (2.14E+01)	3.27E+01 (9.48E+00)	2.24E+01 (4.66E+00)	3.0E+02
Nitrate	7.73E+05 (1.14E+05)	2.32E+06 (2.79E+05)	2.24E+05 (8.53E+04)	3.5E+06

Table 5 – $D_{\text{food intake}}$ [kg per person] calculated with the Equation 7

Date	Name	Badhoevedorp	IJPlein	Ranonkelkade	Wageningen
Week 19 - 2017	Cd	4.85E-01	5.15E-01	6.18E-01	5.23E-01
	Hg	1.02E+02	8.40E+01	1.02E+02	1.02E+02
	Pb	9.79E+00	6.99E+00	3.31E+00	1.11E+01
Week 23 - 2017	Cd	3.46E-01	3.80E-01	3.80E-01	3.46E-01
	Hg	1.33E+02	1.23E+02	1.60E+02	1.33E+02
	Pb	1.19E+01	6.37E+00	5.71E+00	9.78E+00
Week 28 - 2017	Cd	4.33E-01	4.02E-01	5.29E-01	4.28E-01
	Hg	1.30E+02	1.13E+02	1.69E+02	1.13E+02
	Pb	1.38E+01	8.52E+00	1.07E+01	1.38E+01

4.3.2 Modelling

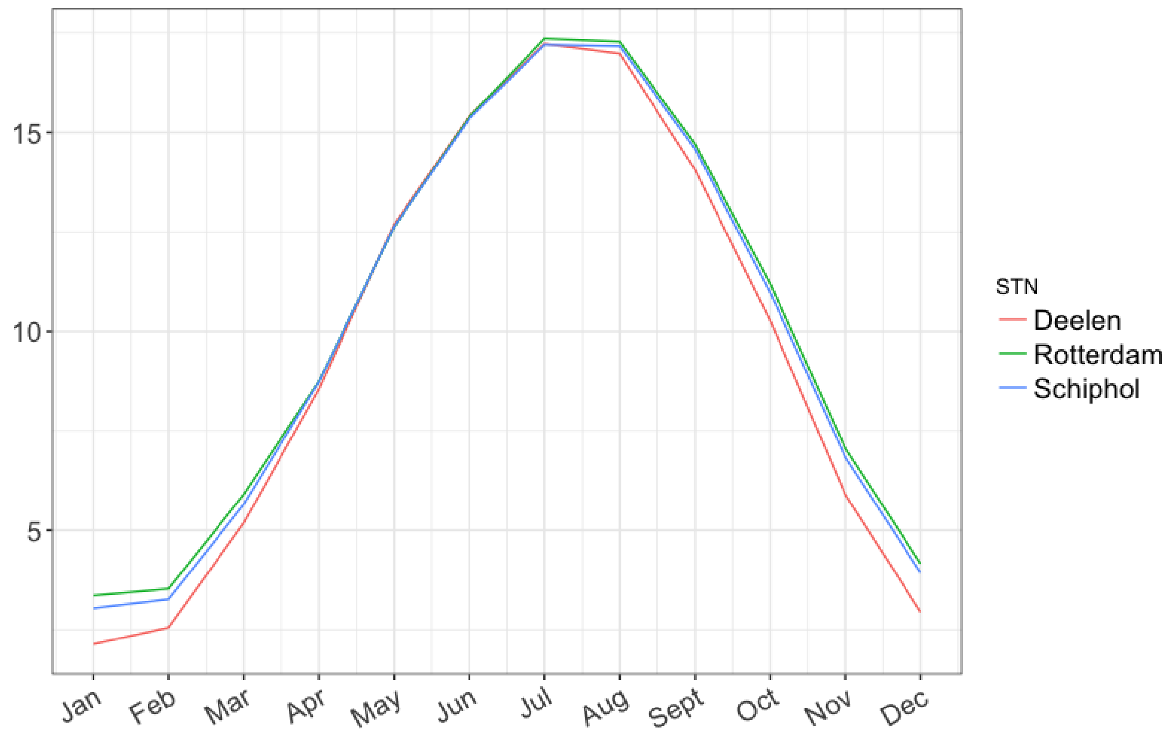
- Environment characteristics of the city of Amsterdam - R

  Figures 6a and 6b describe how the temperatures evolved the past decades, in the cities (Amsterdam and Rotterdam) and in the countryside (Deelen station). There was a global linear increase in temperature for the three stations (Fig. 6b). Rotterdam endured the highest temperatures over the years but also on monthly average. The difference between city and countryside temperatures was more important during winter and almost null during the spring and summer (Fig. 6a).

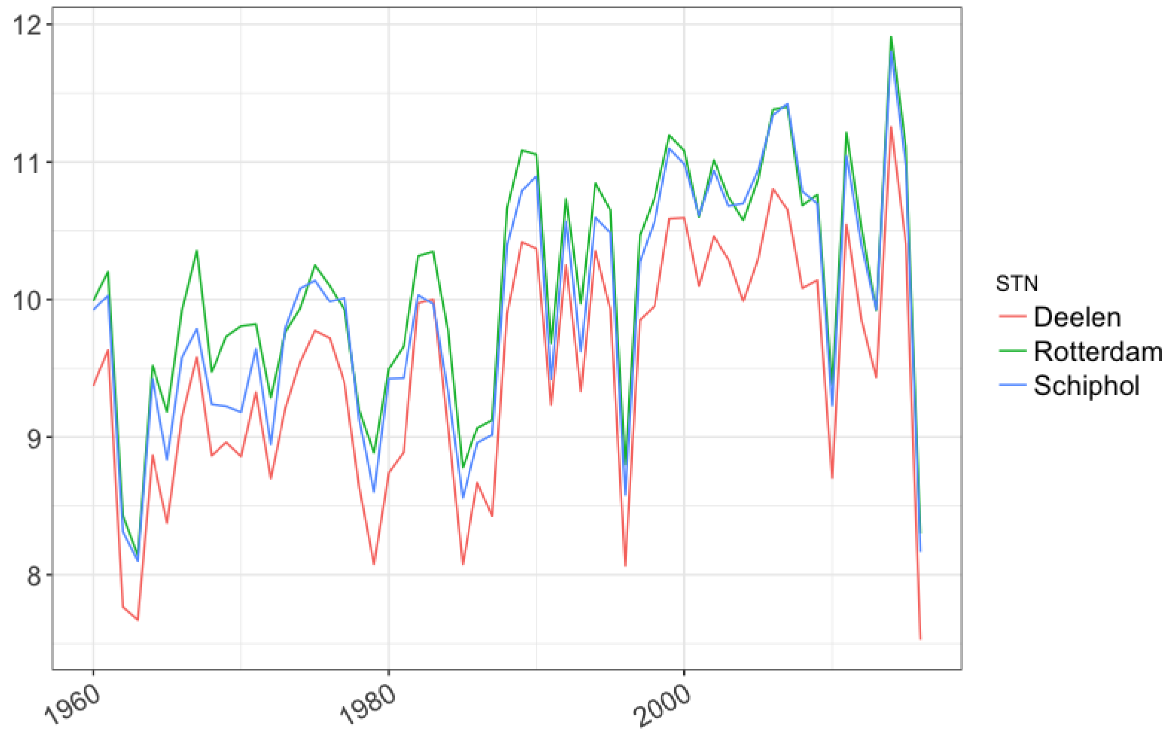
  Figure 7a shows the time series for NO, NO_2, NO_x, CO, $PM_{2.5}$, PM_{10} and O_3 in three sites situated in and around Amsterdam: Badhoevedorp, Nieuwendammerdijk and Van Diemenstraat. The data were not continuous over time. For instance, there was a gap for Badhoevedorp without any data from the 6 April to the 1 May. At first glance, data look quite continuous, homogeneous over time. However, Van Diemenstraat site exhibited stronger variations for NO and NO_2 compared to Badhoevedorp and Nieuwendammerdijk. Nieuwendammerdijk has particularly very low concentrations and variations of NO compared to the two others. For some pollutants, some peaks of concentrations can be identified, as for PM_{10} in Van Diemenstraat where the concentration reached 139.7 $\mu g/m^3$ the 12^{th} of May. The average hourly distribution of the pollutants (Fig. 7b) shows some of the air pollutants' specific patterns, especially in urban areas where there was a higher traffic the morning at around 8:00 am and late afternoon, during the week days. In Badhoevedorp, the concentration of $PM_{2.5}$ was higher during the week-ends compared to the week days (Fig. 7b). However, it is important to keep in mind that these statistics are highly dependent on the number of concentrations and data available. Indeed, the average concentration of $PM_{2.5}$ was only based on the first five days of April for Badhoevedorp. Van Diemenstraat had more data over time, therefore, its results were more relevant. During the week days, CO, NO, NO_2 and NO_x had a peak of concentration around 8:00 am. The NO_x peak occurred for a shorter period and a little bit later than NO and NO_2. O_3 is a very strong oxidising agent, resulting from reactions involving VOCs and oxides of nitrogen (NOx) in the presence of sunlight. As it is a photochemical pollutant, O_3 is formed only during daylight hours under appropriate conditions but is destroyed throughout the day and night.

- Dispersion & deposition modelling - Ansys Fluent v18.0

  For the urban environment, the calculation time was about 10 hours. The following minimum values were reached after 6,000 time steps (time step size of 0.05 s, corresponding to a flow of 300 s): 4,2E-05 for the turbulent kinetic energy (k), 4.6E-05 for the dissipation (ε), 9.4E-05 for continuity, 1.0E-10 for energy, 4.7E-06 and 2.7E-06 for X- and Y-velocity. The simulations were run on a longer time to be certain of the stability of the residuals. Figure 8 gives the residuals after 8,500 iterations, showing a solid and steady state. Apart from a small jump around 3,700 iterations corresponding to the moment when the particles touch the garden for the first time, the residuals decreased continuously. Figure 9a displays the velocity magnitude of the wind for the urban building configuration. As the wind was set perpendicular to the street, high disturbances were engendered once the flow reaches a building. The first 30 m above the buildings exhibit strong wind velocities, with a maximum of 5.73 m/s. The flow over the urban canopy was highly disturbed the first 100 m after the first building. The street, as well as the garden, exhibited lower velocities as being protected from the background wind by the

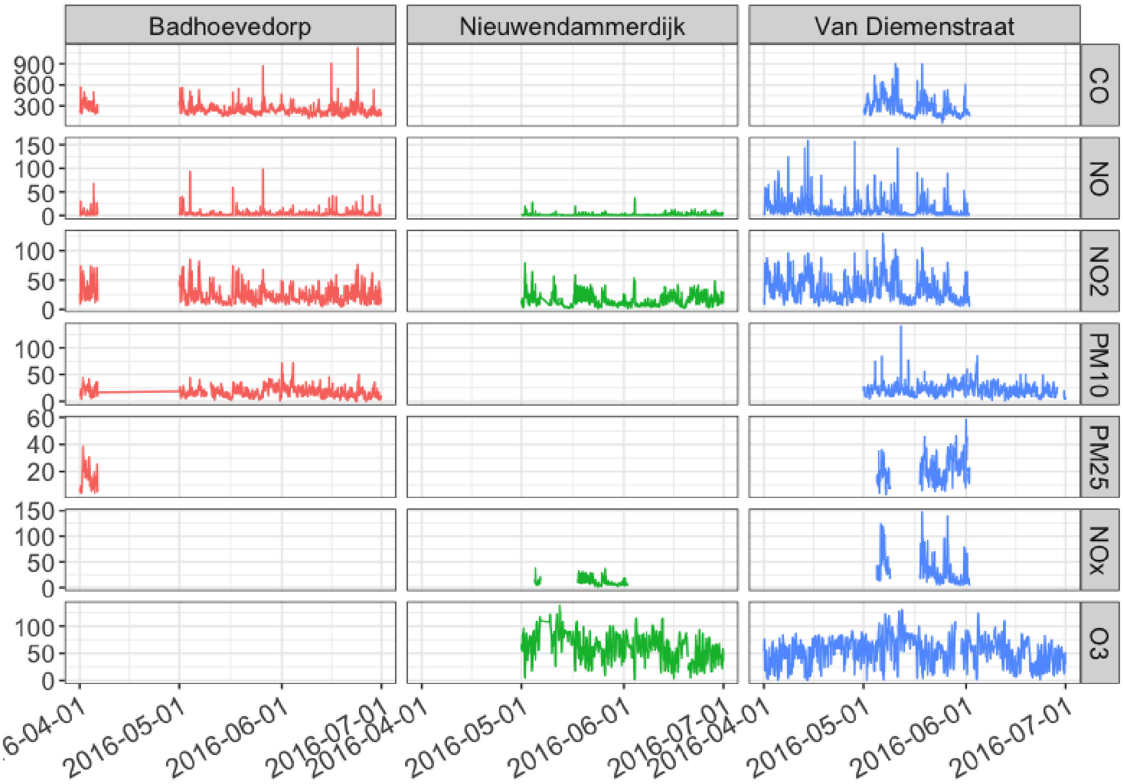


(a) Average temperature over 1960-2016 period

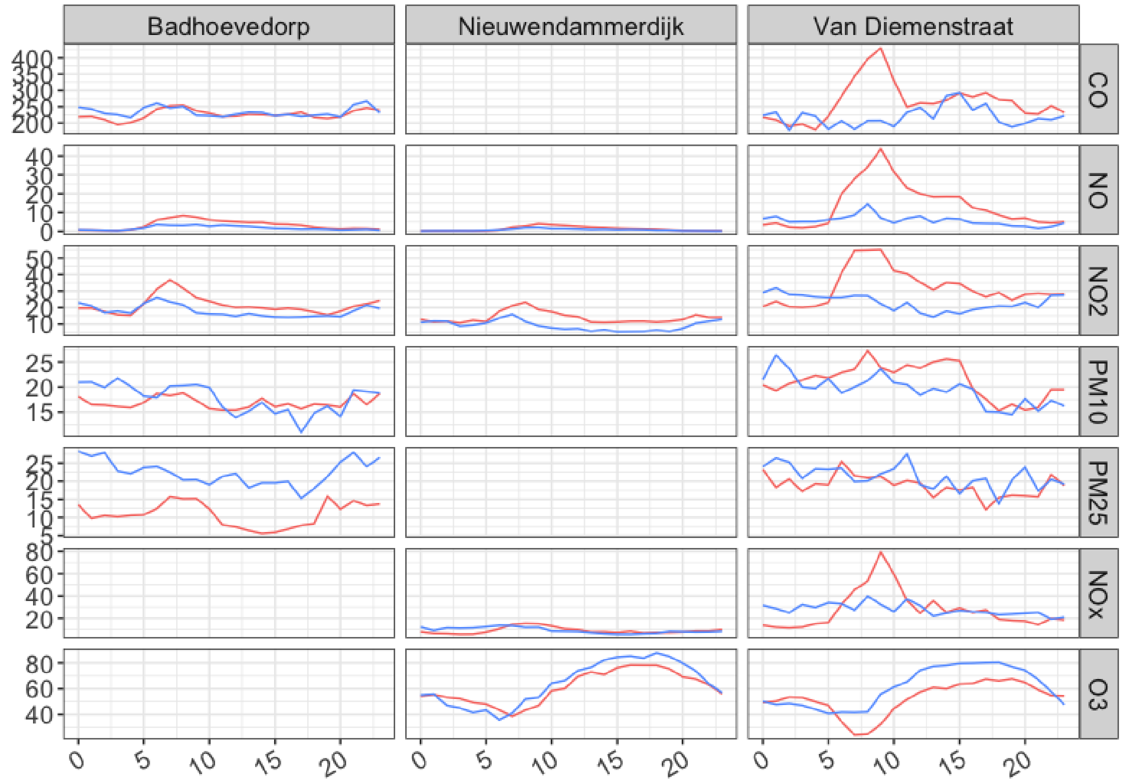


(b) Year average temperature time series over 1960-2016 period

Figure 6 – Statistics on temperature



(a) Concentration time series of several air pollutants during spring 2016 [µg/m^3]



(b) Hourly distribution of air pollutants in function of the day type during spring 2016. The concentrations are in µg/m^3, in red for the days of the week, in blue for the days during the week-end.

Figure 7 – Statistics on air pollutants

urban canopy. The particles injected from the background (left inlet) entered the street canyon and the garden (Fig. 9b). In the street canyon, the accumulation was on the edges (Fig. 9b). A clockwise vortex can be identified in the garden, with higher velocities near the buildings and the surface (Figures 9a, 9b). The particle velocities over the Y-axis are reported for the garden, in Figure 9c. If the velocity was mainly null for the fields, the roads exhibit positive and negative velocities, due to the induced turbulence by the traffic emission. On the buildings, the variability was much higher than the other walls (field, road, garden), owing to their height, obstructing the air flow. On the garden, the particle Y-velocity was negative on the leeward side (up to - 0.095 m/s), suggesting deposition of PM and positive on the windward side, due to the clockwise circulation of the flow. The maximum concentration in the garden was 1.8E-04 kg/m^3, observed at 222 m, but the area weighted average was one order of magnitude lower: 6.0E-05 kg/m^3. The deposition of PMs was unequally distributed, they deposited mostly on the leeward side. Overall, only a very small fraction of particles accumulated on the garden, the amount after 300 s corresponding to 1.0E-07 of the total particle volume fraction. The majority of the particles was in the air, transported by the flow.

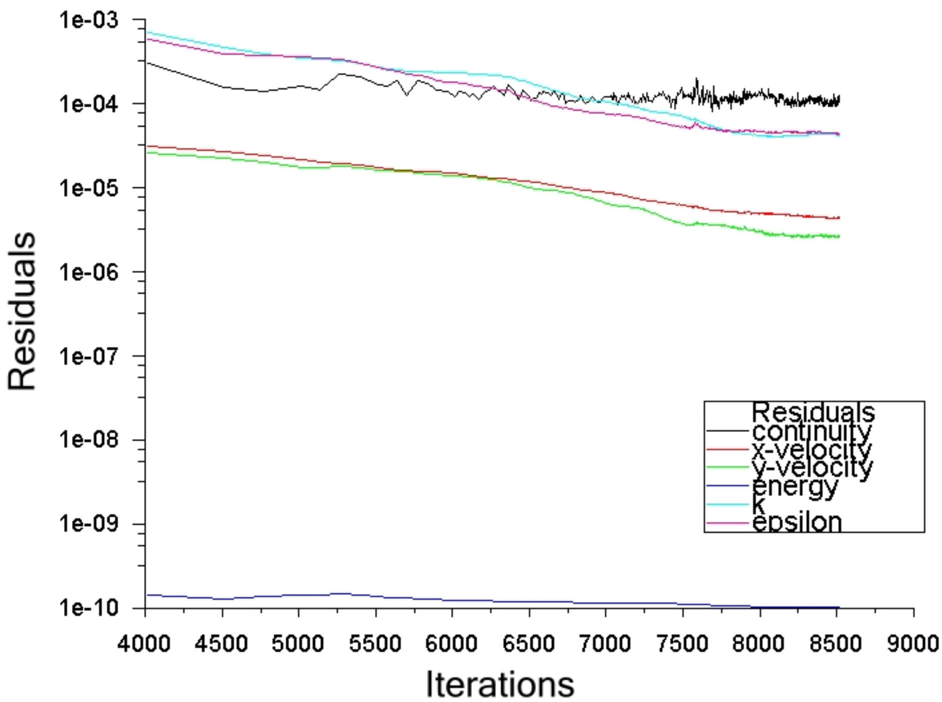
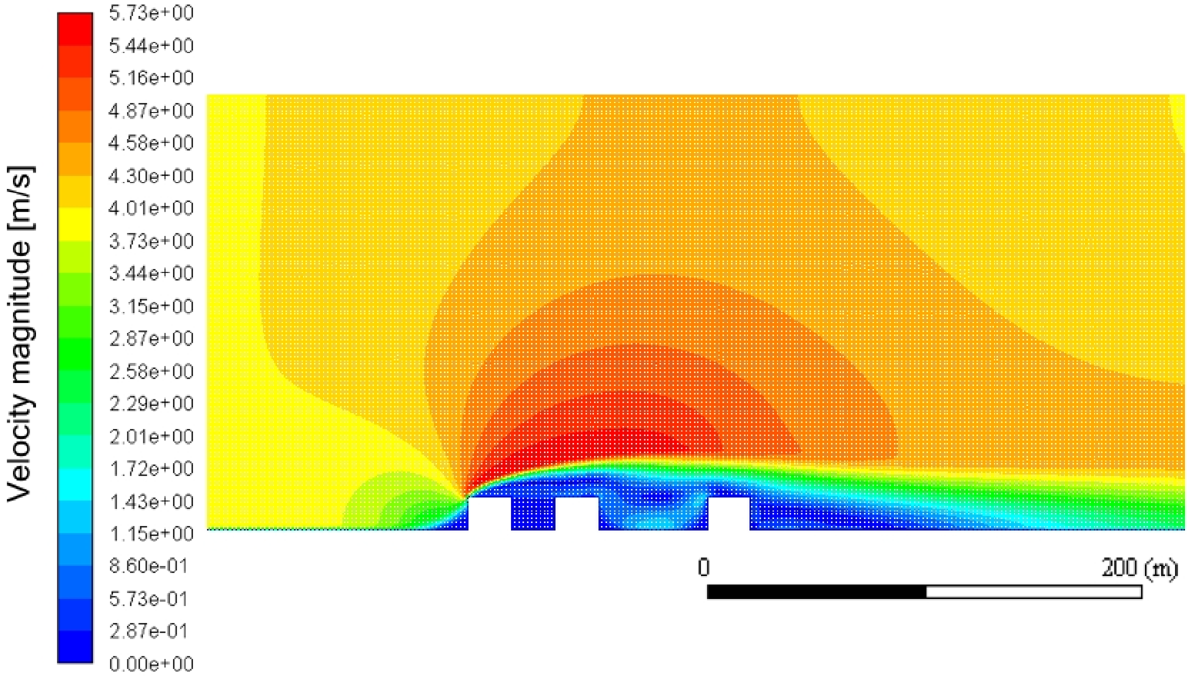
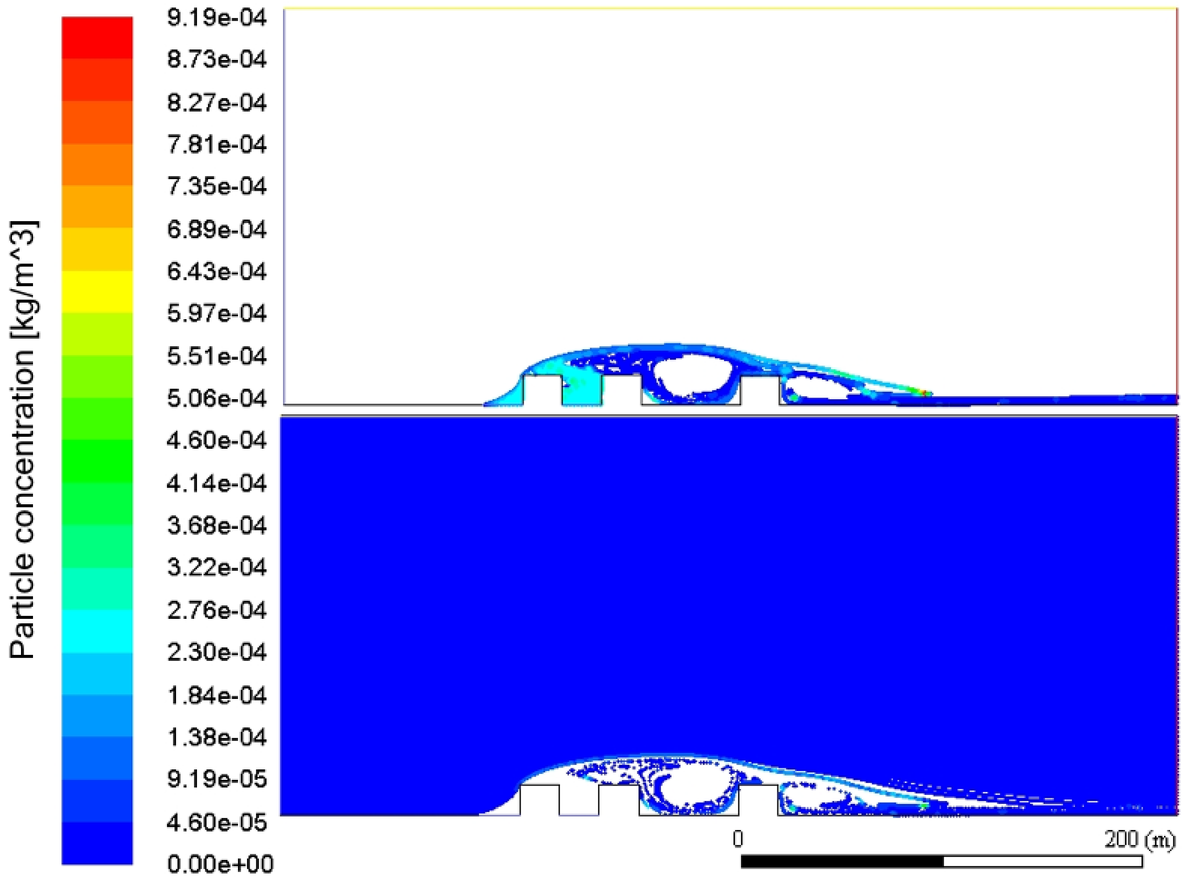


Figure 8 – Residuals after 8,500 iterations for the urban configuration (logarithmic scale on the Y-axis)

For the rural environment, the same figures are given in the Appendix F (Figures 17, 18a, 18b and 18c). The calculation time was about one hour, with a time step of 0.05 s. The following residuals values were reached after 6,000 iterations (300 s): 5.7E-12 for k, 4.3E-13 for ε, 1.0E-10 for continuity, 8.6E-17 for energy, 3.9E-10 and 3.1E-13 for X- and Y-velocity. As seen in Figure 17, the residuals stabilised after about 5,000 iterations. As the configuration is more simple and because there is no urban configuration disturbing the flow, the wind velocity was uniform (Fig. 18a). However, the flow velocity (Fig. 18a), as well as the particle Y-velocity (Fig. 18c), decreased in the vicinity of the garden due to its higher roughness parameters. The particle concentration was higher on the

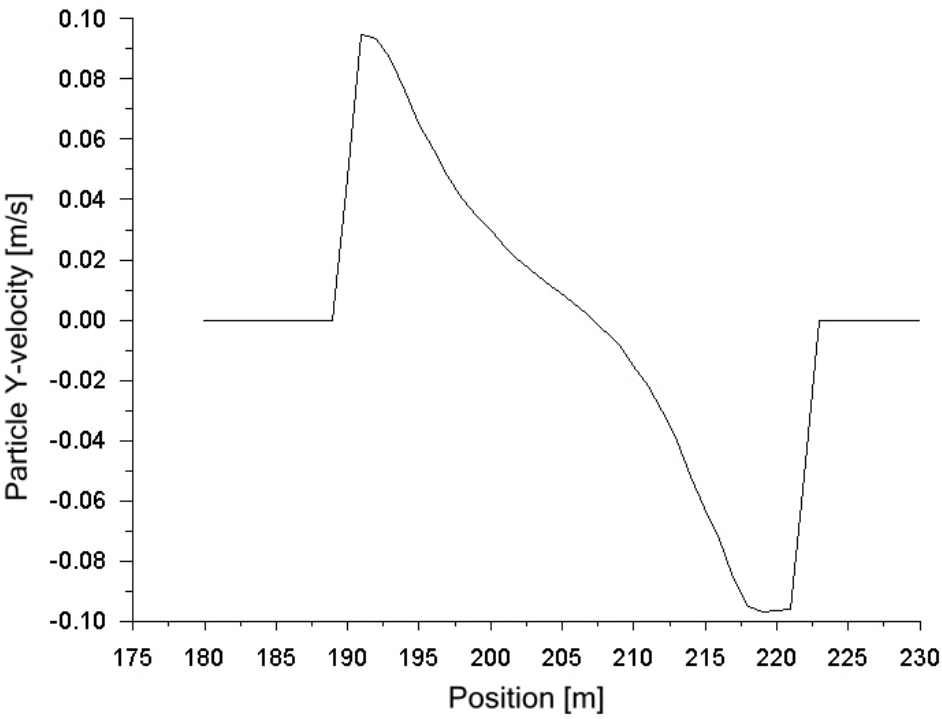


(a) Wind velocity magnitude [m/s]



(b) Particle tracking emitted from the traffic (top) and background emissions (bottom), coloured by their concentration level [kg/m^3]

Figure 9 – Results of the simulations for the urban design after 6,000 time steps



(c) Particle Y-velocity [m/s] along the X-axis [m], corresponding to the garden

Figure 9 – Results of the simulations for the urban design after 6,000 time steps

garden and on the field following the garden (Fig. 18b). The maximum concentration on the garden after 6,000 iterations (300 s) was 3.2E-06 kg/m^3, which is two orders of magnitude smaller than the one observed in the urban configuration. However, it is noteworthy to precise that the urban configuration has an additional source of emissions, a higher input width (meaning a higher number of particles emitted from the input). The particle Y-velocity was positive but very small in the rural garden (Fig. 18c) compared to the urban configuration.

For the urban and rural configurations, the model was launched several times to obtain the convergence of the calculation, with low residuals, mass imbalance. I swept the input parameters to observe their influence and the results are summarised in Table 6. Each simulation was compared to the reference simulation described in Methods (section 3.3.2, Table 2), for which all the results are explained above. The air temperature was swept from 281.16 K, to 285.16 K and 288.16 K, in correspondence to the spring monthly average in Amsterdam (Fig. 6a). Changing the temperature resulted in minor changes, the same flow patterns were observed (static pressure, velocity magnitude, particle Y-velocity on the garden). Nevertheless, the area average concentration in the garden was slightly lowered but its standard deviation is quite high (5.9E-05 kg/m^3). Furthermore, increasing the traffic particles diameter resulted in a lower average concentration on the garden, with a smaller minimum Y-velocity (-0.08 m/s). Increasing the time step size led to higher residuals, not respecting of $< 10^{-4}$ the limit I set (section 3.3.2).

Table 6 – Results of the simulations, after 6,000 iterations, when sweeping the input parameters for the urban design in Ansys Fluent. Cells coloured in red correspond to the reference values for which all the other simulations were compared.

Parameters		Results
Air temperature	281.16 K	On the garden: minimum Y-velocity -0.11 m/s at 220 m, maximum concentration: 1.7E-04 kg/m^3 observed at 217 m, average concentration: 2.5E-05 kg/m^3
	285.16 K	On the garden: minimum Y-velocity -0.10 m/s at 221 m, maximum concentration: 2.5E-04 kg/m^3 observed at 212 m, average concentration: 5.7E-05 kg/m^3
	288.16 K	On the garden: minimum Y-velocity -0.10 m/s at 222 m, maximum concentration: 1.7E-04 kg/m^3 observed at 210 m, average concentration: 6.0E-05 kg/m^3
$d_{\text{road particles}}$	1.0 µm	On the garden: minimum Y-velocity -0.10 m/s at 222 m, maximum concentration: 1.8E-04 kg/m^3 observed at 210 m, average concentration: 6.0E-05 kg/m^3
	2.5 µm	On the garden: minimum Y-velocity -0.08 m/s at 219 m, maximum concentration: 4.9E-05 kg/m^3 observed at 207 m, average concentration: 1.0E-05 kg/m^3
	10 µm	On the garden: minimum Y-velocity -0.04 m/s at 212 m, maximum concentration: 8.7E-05 kg/m^3 observed at 198 m, average concentration: 1.2E-05 kg/m^3
Time step size	0.1 s	Residuals above 10^{-3}
	0.05 s	Solution converging, residuals below 10^{-3}
	0.01 s	Solution converging, residuals are below 10^{-4}

5 Discussion

5.1 State of the art

Literature assessing both air pollution and UA is still scarce but even so, some major patterns could be identified from the previously cited literature (see 4.1):

- The studies used different vegetable crops but a common practice was to adopt leaf vegetables to assess the maximum health risks, as being well-known to accumulate many compounds such as heavy metals.
- Traffic is the most relevant source of metal accumulation in vegetables.
- The concentrations almost never exceeded the different international standards.
- One way of answering to the air pollution issue is to carefully plan urban gardens. For example, the implementation of trees can form a natural barrier and protect the urban horticulture.

It was difficult to compare the results of the different research and to draw conclusions about it as the methods they employed to analyse UA food was diverse from one study to another. For instance, many sampled directly urban gardens. It adds another variable to the system as soils present high spatial variability and may be potentially contaminated. Aside from the methodological issue, the conditions (meteorological, topological, air quality) differ greatly between the countries and cities. Therefore, it was very important of studying/monitoring carefully, for every specific location, the foodstuff contamination in order to avoid any risks on human health security.

Finally, the air pollution seems to preoccupy scientific researchers. The recent boom of urban green initiatives has been requiring further research on their pollutant up take, as a way to clean the air. Turning the "green pollutant up take potential" the other way around, the concern and disquietude about the ingestion risks from UA may have emerged. From now on, the quality of the urban crops is globally similar to the rural one. However, when UA is close to a traffic source, it results in higher trace concentrations. The spatial design of urban gardens is of a major importance to ensure good crops quality.

5.2 Interviews

The global awareness of citizens and municipalities on soil pollution is quite high. In Groningen, the soil is systematically tested in order to assess whether it can welcome a vegetable garden. In Amsterdam, it is possible to perform tests if one is doubting on the soil pollution. However, the situation differs for the air pollution. It seemed that the municipalities are conscious of the traffic pollution and its successive risk of mediocre air quality in street canyons. Yet, they are less familiar with the global background air pollution, and its possible impact on the food grown in cities. On the other hand, the link between the air monitoring department and the health department, the urban planning department (which includes the greening of the city) in the municipality is not clear. Two explanations can be given for this lack: firstly, the scientific data and expertise on the air pollution risk focusing on urban gardens are too scarce, the municipalities and the policy makers are not aware of the risks and possibly do not feel concerned, estimating that their city is globally clean. It is worth mentioning that maybe the policy makers are right and they should not preoccupy because the risks of air pollution on UA is minor. The second explanation could be that as UA is highly valuable and fruitful for the citizens and the well being of the people, the possible threat of urban contamination is put aside, after all its potential advantages for urban society. However, it is important to mention that these assumptions are based on only three interviews, for more evidence this issue should be far more deepened.

5.3 Bio-monitoring and modelling

5.3.1 Bio-monitoring

Spinach plants were cultivated in containers, with unpolluted standard soil. Indeed, the air pollution was targeted, considering that the pollutants in above-ground organs were the results of aerial uptake. Heavy metals, nitrate and 16 PAHs were measured, being relevant in term of urban air pollutants and plant uptake. Furthermore, indicative background levels of cadmium, mercury and PAHs were calculated from previous bio-monitoring programs in rural Netherlands in order to highlight the longer trends and average rural background concentrations in spinach plants. The concentrations were also compared to legal limits in foodstuffs to compare the "natural" vs. urban levels. As a final point, the risk of ingestion was assessed, calculating the maximum amount of spinach plant that should be daily ingested in correspondence to a TDI exceedance.

For the heavy metals, the variations were mostly observed per period rather than per sites. No global trends could be identified from one site to another in Amsterdam, nor with Wageningen. Yet, the first experiment showed slightly higher values than the two other ones for copper, lead and mercury. The values observed for Cd and Hg were in the same range of values obtained by van Dijk et al. (2015) during their multiple years (2004-2013) bio-monitoring programs. For Cu and Pb, it was more difficult to draw conclusions as I had no long-term background references. Adding the IQR range, the minimum/maximum of the rural background values, as well as the legal limits, tend to re-scale the data and one has to be careful not to misinterpret the results without them. Referring the scientific literature, the concentrations were low for all the periods. The legal limits for European/international merchandising were never exceeded. Some of the variations of the heavy metals levels between the exposure periods can be explained by differences in weather conditions: the period marked by low precipitation having more dry deposition of PM compared to the rainy periods, where the wet deposition occurs but also washed out the pollutants from the leaves. Globally, it seemed that the sites in Amsterdam, and especially northern Amsterdam, had higher variations during the season, compared to Wageningen. However, no distinction in between the urban sites, nor between the urban and rural sites, could be truly identified during this study.

In leaf vegetables, the nitrate concentration range is known to be very wide due to the different cultivation characteristics (N-fertiliser application, use of herbicides, soil types, etc) (Iammarino, Di Taranto & Cristino, 2014). Plants usually absorb nitrogen through their roots but the particle deposition of nitrate and other nitrogen compounds can represent a substantial fraction of total nitrogen reaching vegetation. However, the foliar uptake mechanisms are not well-known (U.S. Environmental Protection Agency, 2005). An additional determinant factor for the presence of nitrate in spinach is the climate and particularly the light conditions. The higher the light intensity, the lower the nitrate concentration (Colonna, Rouphael, Barbieri & Pascale, 2016; Proietti, Moscatello, Giacomelli & Battistelli, 2013). However, the concentrations increased noticeably between the first and second period, for all the sites, including the rural background in Wageningen. It could be that as the first period was on a longer time on field, the spinach had already up taken most of the nitrate and it was deficient in the soil. Yet, during the third period, all the concentrations were even lower than the first period, confirming the high uncertainties about nitrate up-take and cycle in the plant.

PAH levels in crops are correlated to seasonal fluctuations corresponding to the variations of local air temperatures and particle concentrations. During periods with lower temperatures, PAHs increase due to heating and combustion processes. It also leads to increasing condensation of PAHs on airborne particles (van Dijk et al., 2015). An additional factor that could affect the heavy metals and PAHs concentrations in the plants is the closing of the stomata in order to limit gas exchange when the temperatures are high. Therefore, it was surprising to observe a global increase for most of the PAHs (also discernible with the total 16 PAH concentrations) between the two first periods, as the second period was marked by an acute heat wave and had been on field for four weeks (compared to 8 weeks for the first period). Differences could be pinpointed, for some PAHs where concentrations were systematically higher, with a higher variability, for the first two periods, in Amsterdam (benzo(a)anthracene, benzo(b/j)fluoranthene, benzo(ghi)perylene, chrysene), likely in relation to the traffic emissions. The last period experienced low variations per site, the concentrations being also particularly lower than the two previous results and the 10-years rural bio-monitoring. It could be due to general lower PAHs concentrations in the atmosphere due to higher precipitations, removing a significant part of PAHs via wet deposition (Q. Wang et al., 2016). Furthermore, the PAHs levels in Wageningen were more similar to the rural background ones, being mostly in the IQR. However, for some PAHs (acenaphthene, acenaphthylene, anthracene, fluoranthene, indeno(123cd)pyrene, naphthalene, phenanthrene, pyrene), the levels were similar for all the sites, for each period, suggesting resembling background concentrations. Yet, the concentrations were still low compared to the bio-monitoring project results of van Dijk et al. (2015). They observed fluctuations in PAH levels in correspondence to the global background concentrations.

As an indication from this bio-monitoring program, the amount of spinach that can be safely ingested on daily basis is of about 500 g of spinach. This value was based on cadmium maximum level. Regarding lead and mercury, the amount of spinach would be of several kilos. Moreover, a diet is not constituted by an exclusive consumption of spinach. Spinach is a good bio-monitor and therefore contains high levels of heavy metals, but consuming a wider diversity of vegetables lowers the heavy metals (dietary) uptake.

Last but not least, it was relieving to see that the concentrations of the contaminants on the spinach we grew did not differ significantly from one site to another in Amsterdam but also comparing rural and urban environment. It was good news for the gardeners, comforting them about their urban crops, about the air quality in Amsterdam. A first assumption explaining the few differences may be that the global air had a good quality during the bio-monitoring period and that the punctual sources of pollution did not have a significant impact being too far away from the gardens. The quality of the air can be judged with the Air Quality Index. It was generally good to moderate during the period of study (Common Information to European Air CITEAIR, 2007). Indeed, according to literature, the pollution from the road is meaningful in the first meters next to it, then it decreases exponentially (Säumel et al., 2012). Secondly, it is relevant to summarise the results in relation to the expectations, based on the weather conditions. As the first experiment was on a longer period in the field, I expected the concentrations to be higher, because of a longer exposure and increased possible accumulation time. The weather was favourable, the concentrations could have been higher in Amsterdam. I was surprised to observe higher concentrations for the second period, as spinach was subjected to a heat wave at the beginning of June, and the leaves were often quite dry, sign of dehydration state and closed stomata. Finally, the third period had cooler temperatures, more suitable for the growth of the spinach and gas up-take. As was previously stated, the experiment was realised over a three-month period, which is short to draw accurate global conclusions. One has to keep in mind that the results are highly dependent on the meteorology, on the location. Therefore, this study should be more considered as a pilot, highlighting and raising the possible issue of air pollution in the specific context of Amsterdam, spring/summer 2017. Yet, from the point of view of the gardeners and policymakers, the health security and prevention could become a strong argument for implementing bio-monitoring programs in different cities in the Netherlands. It would eliminate partially the meteorological insecurity, strengthening the results and conclusions.

5.3.2 Modelling

Modelling urban and rural environments aimed at complementing the bio-monitoring program. CFD is a powerful tool that offered an insight into the dispersion, wind-vector flow and resulting pollutant levels in gardens in different contexts. If the behaviour of urban systems has been studied, the results depend highly on the configuration of the city, the meteorology and pollutants level, hitherward of Amsterdam. Hence, the importance of first retrieving some information specific to its environment, air quality. One of the outcomes of the CFD simulations is the deposition of particles (velocity and concentration). It was computed in the intention of comparing the concentrations retrieved from the bio-monitoring program with the ones obtained with the model.

With regards to the statistics drawn up with KNMI and Lunch Met Net data with the statistical environment R, about the air quality in the Netherlands, the climate was observed to differ from the countryside to cities. Temperatures were globally higher in cities, and the differences are especially significant in winter (about 1 °C based on a 50 years average). It matches to the "Urban Heat Island" phenomenon, i.e. the exchanging heat processes in cities are different than in the countryside and its natural landscape. The construction materials are dense and the surfaces are characterised by dark colours, low albedo (e.g. asphalt roads) (Arnfield, 2003). Focusing on the air pollutant in and around Amsterdam, the pollutants globally had the same patterns (diurnal, monthly) but the variations are stronger for Van Diemenstraat station, with higher CO, NO, NO_2, NO_x concentration peaks. It could be associated with the burden of road traffic as these were observed at a discernible period during the day (i.e. the morning rush hour from 8 am to 10 am). Lastly, if the statistics gave a visual representation of the global air quality and its trends in the Netherlands, they were also a support for the choice of the CFD input parameters. For the rural design, only background concentrations were given while for the urban design, traffic emissions were further added.

In the same fashion as for the observed meteorological and pollution variability from the urban to the rural environment, the air flow modelled with Ansys Fluent was shaped by the disparate designs. Firstly, for the urban context, the general background wind and particles blew globally above the gardens. However, part of it infiltrated the street canyons and garden, generating vortices. Emissions from the roads also affected the accumulation on the gardens, the particles circulating above the buildings. The particle Y-velocity on the first garden was negative at the leeward side, due to a clockwise circulation of the wind, leading to a higher accumulation at the edge. It was a very high value compared to the ones given by many studies, expressing the need for a better definition of the garden parameters. Voltaggio, Spadoni, Carloni and Guglietta (2016) estimated a deposition velocity of fine PM of 0.9–2.5 mm/s over grasses. The deposition velocity depends on the vegetation characteristics, with most of the values being in the range of 0.02–10 cm/s (Xue & Li, 2017). Yet, in literature, special calculations are used to retrieve the velocity of deposition, as being the quotient between the mass particle flow rate towards the leaf surface and the measured atmospheric mass concentration (Voltaggio et al., 2016). When looking at the concentrations on the gardens after the same number of iterations, I observed higher concentrations in the urban design, in relation to more sources of emissions and a higher domain. The concentrations were directly connected to the emission rate I fixed. With a mass flow rate of 10^{-3} kg/s, a maximum concentration of 1.8^{-4} kg/m^3 was observed on the urban garden, being several orders of magnitude above the measured concentrations of heavy metals in the spinach. Defining correctly the particle matter mass flow rate presented difficulties, hence the decision of fixing the mass flow rates to 10^{-3} kg/s and analysing the results in correspondence. If the mass flow rate may be such at the exit of the car exhaust, it is quite unlikely to observe such a number in reality, for the whole street width. Yet, using the same mass flow rate for the background and road was a way to assume the equal contribution of each source to the city air pollution. Secondly, the rural background design was influenced by the change of roughness parameters of the garden. The non-presence of disturbances (buildings, roads) engendered regular wind velocities in all the environment. The roughness parameters of the garden decreased locally the wind magnitude, inducing a higher deposition on the subsequent field. Sweeping parameters strengthen the comprehension of the results, being in line with the scientific knowledge on the aerosol deposition. I observed relatively small differences in terms of aerosol deposition when modifying the temperature of a few degrees. Temperature is an important factor when considering the formation of the secondary aerosols. Increasing temperatures are in favour of higher gas-phase reaction rates, leading to higher ozone and secondary aerosols concentrations (Aw & Kleeman, 2003). As the particles modelled were set to be inert, the chemical reactions were not included, explaining, therefore, the poor impact of temperature. The concentrations on the garden decreased with decreasing particle diameter. However, the air flow remained mostly unchanged.

It is noteworthy mentioning the limits of the modelling part as well as some recommendations to improve it:

1. Firstly, focusing on the geometrical environment, CFD modelling is greatly influenced by the spatial design and heterogeneity (De Giovanni et al., 2015). The urban environment was designed based on one neighbourhood of Amsterdam which has similar patterns, regular heights. Yet, as seen with the modelling, the air flow is easily perturbed by buildings on a very long distance. The ideal would be to model a larger environment, more rigorously (e.g. using GIS), including several streets and buildings, but it would require more CPU and a large amount of computer memory (Ren & Stewart, 2003). Indeed, the impact of air pollution and particles deposition on UA is seen at a very small scale and a fine mesh is mandatory for accurate results. Moreover, the design suggests that the direction of the wind is at 45 angle compared to the street angle, corresponding to the maximum effect. However, in reality, the direction of the wind is not uniform. There are diurnal variations, the flow can be channelled in the streets, affecting the dispersion and deposition phenomena (Janhall, 2015).

2. Secondly, regarding the mesh, more precise results could be obtained if it was finer (ANSYS Inc, 2016). Nevertheless, the time required to run one simulation was already too long to perform finer meshes over the project period.

3. Now looking at the model input-parameters, one option to better describe the pollutants is to create its own user defined function (UDF). However, it increases the complexity of the project, that is why I chose to use the existent parameters, opting for an inert particle, the most similar to PM. Yet, using PM with a defined diameter is also subject to debate, the concentrations, size distribution, structure and chemical composition of aerosol particles fluctuating greatly, spatially and temporally (Lagzi et al., 2013). In order to represent the air pollution and compare the model to the bio-monitoring results, a set of particles could be defined, relating the different particles to each measured contaminants. For example, Lagzi et al. (2013) discuss the size distribution in relation to the chemical composition of particles and relate trace metals mostly to particles with a diameter lower than 1 µm; nitrate to the particles with a diameter higher than 0.1 µm. For both, it is important to also precise that they are not the only/major constituents of the PM but they are the one relevant for this project, in terms of plant up-take and accumulation. The size distribution also has to be connected to the way they sink on the garden: if particles larger than 0.1 µm deposit via sedimentation (dry deposition), for the coarse particles (0.1 µm > d > 1 µm), the Brownian diffusion is the most important process, etc (section 2.3.2).

4. On the other hand, concerning the method used to evaluate the pollutant deposition and therefore compare it to the bio-monitoring results, it could be improved in several ways by: comparing the magnitude of resistances for particles (aerodynamic, canopy and the parallel gravitational settling).

   Finally, as shown in Figure 10, an important part of the process, from the modelling to the bio-monitoring results, was missing. Indeed, the plant up-take mechanisms are not implemented in Ansys Fluent. It is another variable difficult to assess owing to the fact that it is plant-specific dependent but also relative to the environment, the air pollutants and their concentrations, the meteorology, etc (section 2.4).

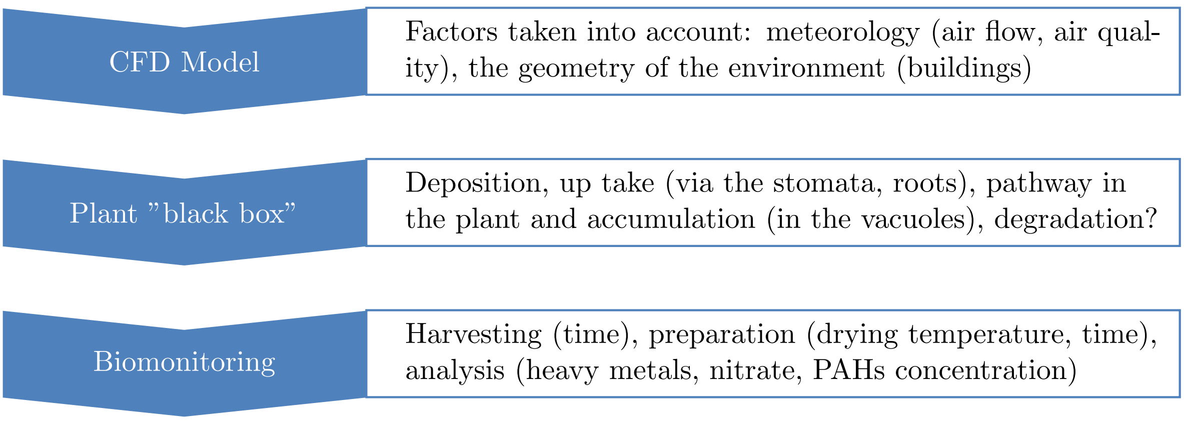


Figure 10 – From the model to the results, the gap of the plant up take mechanisms representation when comparing the model and biomonitoring results.

To conclude, modelling the environment using CFD added value to the bio-monitoring program. Yet, it would require further work to truly support the results of the bio-monitoring. According to the results of the CFD modelling, I expected to have higher levels of heavy metals in Amsterdam than in Wageningen, with greater accumulations on the leeward sides of the garden and street canyons.

6 Conclusions and recommendations

The popularity of UA has led to an increased concern about the possible negative impacts of its environment, from the soil pollution to the quality of the air. This Master Thesis aimed at quantifying the risk of air pollution on UA.

In the first place, the status of the scientific knowledge on UA and air pollution was appraised. Only a few studies tackle both topics together. Nevertheless, some global trends could be observed: the international standards for foodstuff are mostly not exceeded in UA but the pollutants' levels are higher in the vicinity of busy roads. Secondly, I interviewed policy makers in several cities of the Netherlands. The planning of UA initiatives in relation to the contamination risks was evaluated. I observed a lack of regulations and actions from the government when targeting air pollution, whereas the soil contamination is far more assessed and monitored for the land use planning. Unfortunately, I could only realise three interviews. However, I was pleased to see the interviewees were intrigued by this project, as I titillated their curiosity when explaining my research. They gave me a delicate *aperçu* of the needed procedures for the establishment of green initiatives in an urban context. The municipalities highly encourage these initiatives, mindful of its high social impact. Lastly, a bio-monitoring program was pursued in community gardens over a three-month period, in Amsterdam. Plants, and especially bio-accumulators have the capacity to act as precocious sentinels for the risk of air pollutant exposure. Spinach was grown in containers with uncontaminated standard soil and then analysed for its heavy metal, nitrate and PAHs contents, as all being related to urban air pollutants and relevant in terms of plant up-take. This study has shown that some PAHs experienced higher values and variability in an urban context. It could be associated with the car emissions. Yet, the concentrations were low compared to the previous 10-years bio-monitoring program performed by Wageningen University & Research in rural Netherlands. The levels were also below the legal limits, as far as available, given by the European Commission and Codex Alimentarius. As the air pollutant concentrations in food depend on the urban design, on the air quality, on the meteorology; CFD modelling was used to design Amsterdam urban environment and simulate the air pollutants flow. Buildings affected greatly the air flow, inducing turbulence, and the pollutants tended to accumulate on the road sides and on the leeward side of the garden. However, only a very small amount of particles appeared to deposit on the garden.

I believe that the methodology presented offered a complete overview, from the literature assessment to the Dutch policy makers' awareness and the on-field bio-monitoring program. Yet, it is not without any limitations. To perform a better analysis of the policy makers' awareness, it would be recommended to interview more policy makers. Furthermore, the results and conclusions about the bio-monitoring were constrained by its short term period. Long term data would erase, at least partially, the effect of the meteorology and yearly variation of the results. Finally, besides its high potential, CFD modelling is highly sophisticated and necessitates a tactful configuration. Indeed, it is highly dependent on the input parameters. More accurate results could be obtained using UDFs to characterise the situation more precisely. CFD modelling is highly time-consuming with regards to the set-up of the input parameters, to the running of the simulations and to the interpretation of the results.

Consequently, I would recommend for the policy makers and citizens to keep in mind the lack of knowledge on the issue of air pollution on UA. Some measures can be implemented to counter it: with an intelligent spatial planning of UA (avoiding the locations in the vicinity of urban pollution sources, main roads, highways, etc) or the implementation of natural barriers (trees and bushes that have the capacity to absorb PM). For the gardeners, a good precaution is to wash thoroughly the harvest before consuming it.

Given these points, I hope that this study will lead to further clarifications, that it will give a boost to the scientific community to continue the research and to clarify and quantify the lack of knowledge and uncertainties. It is noteworthy to emphasize that, even if the knowledge was there, building bridges with it and with policy makers, informing the population, is of a great importance. The citizens are willing to do their best to protect their harvest whilst keeping growing food in their garden, and this dynamic should be popularised and promoted.

References

Agency for Toxic Substances and Disease Registry (ATSDR). (2004). *Toxilogical profile for copper.* Atlanta: Department of Health and Human Services, Public Health Service.

Amato-Lourenco, L. F., Lobo, D. J. A., Guimarães, E. T., Moreira, T. C. L., Carvalho-Oliveira, R., Saiki, M., ... Mauad, T. (2017). Biomonitoring of genotoxic effects and elemental accumulation derived from air pollution in community urban gardens. *Science of the Total Environment*, *575*, 1438–1444. doi: 10.1016/j.scitotenv.2016.09.221

ANSYS Inc. (2016). ANSYS Help Viewer [Computer software manual].

Antisari, L. V., Orsini, F., Marchetti, L., Vianello, G. & Gianquinto, G. (2015). Heavy metal accumulation in vegetables grown in urban gardens. *Agronomy for Sustainable Development*, *35*, 1139–1147. doi: 10.1007/s13593-015-0308-z

Arnfield, A. J. (2003). Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. *International Journal of Climatology*, *23*(1), 1–26. Retrieved from `http://dx.doi.org/10.1002/joc.859` doi: 10.1002/joc.859

Atelier GROENBLAUW. (2017). *Urban green-blue grids for sustainable and resilient cities.* Retrieved from `http://www.urbangreenbluegrids.com/` ([Online; accessed March 1, 2017])

Aw, J. & Kleeman, M. J. (2003). Evaluating the first-order effect of intraannual temperature variability on urban air pollution. *Journal of Geophysical Research: Atmospheres*, *108*(D12), n/a–n/a. Retrieved from `http://dx.doi.org/10.1029/2002JD002688` (4365) doi: 10.1029/2002JD002688

Bakker, N., Dubbeling, M., Guendel, S., Koschella, U. S. & de Zeeuw, H. (2000). *Growing cities growing food: Urban agriculture on the policy agenda.* Deutsche Stiftung fur internationale Entwicklung (DSE), Feldafing, Germany. Retrieved from `http://hdl.handle.net/10568/63737` ([Online; accessed May 18, 2017])

Barnaby, J. Y. & Ziska, L. H. (2012). Plant responses to elevated co2. doi: 10.1002/9780470015902.a0023718

Bergauer, U. G., Janknecht, S., Wiseman, C. L. S. & Zereini, F. (2011). *Urban airborne particulate matter : origin, chemistry, fate and health impacts.* Springer Berlin Heidelberg.

Bidwell, R. G. S. & Fraser, D. E. (1972). Carbon monoxide uptake and metabolism by leaves. *Canadian Journal of Botany*, *50*, 1435–1439. doi: 10.1139/b72-174

Blocken, B., Stathopoulos, T. & Carmeliet, J. (2007). Cfd simulation of the atmospheric boundary layer: wall function problems. *Atmospheric Environment*, *41*(2), 238 - 252. Retrieved from `http://www.sciencedirect.com/science/article/pii/S135223100600834X` doi: http://dx.doi.org/10.1016/j.atmosenv.2006.08.019

Boening, D. W. (2000). Ecological effects, transport, and fate of mercury: a general review. *Chemosphere*, *40*(12), 1335 - 1351. Retrieved from `http://www.sciencedirect.com/science/article/pii/S0045653599002830` doi: http://dx.doi.org/10.1016/S0045-6535(99)00283-0

Boon, P. E., te Biesebeek, J. D., de Wit-Bos, L. & van Donkersgoed, G. (2014). *Dietary exposure to dioxins in the Netherlands.* National Institute for Public Health and the Environment. Retrieved from `http://www.rivm.nl/en/Documents_and_publications/Scientific/Reports/2014/oktober/Dietary_exposure_to_dioxins_in_the_Netherlands` ([Online; accessed May 2, 2017])

Brown, K. H. & Jameton, A. L. (2000). Public health implications of urban agriculture. *Journal of Public Health Policy*, *21*(1), 20-39. Retrieved from `http://www.jstor.org/`

stable/3343472

Chen, J., Yu, X., Sun, F., Lun, X., Fu, Y., Jia, G., ... Bi, H. (2015). The Concentrations and Reduction of Airborne Particulate Matter (PM10, PM2.5, PM1) at Shelterbelt Site in Beijing. *Atmosphere*, *6*, 650–676. doi: 10.3390/atmos6050650

Chrostowski, P. C. & Foster, S. A. (1996). A methodology for assessing congener-specific partitioning and plant uptake of dioxins and dioxin-like compounds. *Chemosphere*, *32*, 2285–2304. doi: 10.1016/0045-6535(96)00118-X

Colonna, E., Rouphael, Y., Barbieri, G. & Pascale, S. D. (2016). Nutritional quality of ten leafy vegetables harvested at two light intensities. *Food Chemistry*, *199*, 702 - 710. Retrieved from http://www.sciencedirect.com/science/article/pii/S0308814615303460 doi: http://dx.doi.org/10.1016/j.foodchem.2015.12.068

Common Information to European Air CITEAIR. (2007). *Amsterdam - Air Quality Assessment.* Retrieved from http://www.airqualitynow.eu/ ([Online; accessed August 10, 2017])

Council of European Union. (2006). *Council regulation (EU) no 1881/2006.* Retrieved from https://ec.europa.eu/jrc/en/eurl/heavy-metals/legislation ([Online; accessed March 21, 2017])

Craul, P. J. (1985). A description of urban soils and their desired characteristics. *Journal of Arboriculture*, 330–339.

Darrall, N. M. (1989). The effect of air pollutants on physiological processes in plants. *Plant, Cell and Environment*, *12*, 1–30. doi: 10.1111/j.1365-3040.1989.tb01913.x

De Giovanni, M., Curci, G., Avveduto, A., Pace, L., Dari Salisburgo, C., Giammaria, F., ... Tripodi, P. (2015, June). Modelling air pollution abatement in deep street canyons by means of air scrubbers. *ArXiv e-prints*.

de Winter-Sorkina, R., Bakker, M., van Donkersgoed, G. & van Klaveren, J. (2003). *Dietary intake of heavy metals (cadmium, lead and mercury) by the Dutch population.* National Institute for Public Health and the Environment. Retrieved from http://www.rivm.nl/dsresource?objectid=5b1ed314-3559-4916-8172-f9395e56c04b&type=org&disposition=inline ([Online; accessed May 29, 2017])

Dueck, T. & Van Der Werf, A. (2008). Are plants precursors for methane? *New Phytologist*, *178*(4), 693–695. Retrieved from http://dx.doi.org/10.1111/j.1469-8137.2008.02468.x doi: 10.1111/j.1469-8137.2008.02468.x

Dzierżanowski, K., Popek, R., Gawrońska, H., Sæbø, A. & Gawroński, S. W. (2011). Deposition of particulate matter of different size fractions on leaf surfaces and in waxes of urban forest species. *International Journal of Phytoremediation*, *13*(10), 1037-1046. Retrieved from http://dx.doi.org/10.1080/15226514.2011.552929 (PMID: 21972570) doi: 10.1080/15226514.2011.552929

Environmental Data Compendium. (2016). *Quality surface water, 2015.* Retrieved from http://www.clo.nl/node/20740 ([Online; accessed June 14, 2017])

Ericksen, J., Gustin, M., Schorran, D., Johnson, D., Lindberg, S. & Coleman, J. (2003). Accumulation of atmospheric mercury in forest foliage. *Atmospheric Environment*, *37*(12), 1613 - 1622. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231003000086 doi: http://dx.doi.org/10.1016/S1352-2310(03)00008-6

European Commission. (2016). *Air quality and greenhouse gases.* Retrieved from https://ec.europa.eu/jrc/en/research-topic/air-quality ([Online; accessed February 22, 2017])

European Environment Agency. (2014). *Air pollution fact sheet 2014 - Netherlands.* European Environment Agency. Retrieved from http://www.eea.europa.eu/themes/air/air-pollution-country-fact-sheets-2014/netherlands-air-pollutant

-emissions-country-factsheet/view ([Online; accessed May 2, 2017])

European Environment Agency. (2016). *Air quality in europe 2016.* Luxembourg: Publications Office of the European Union, 2016. Retrieved from http://www.eea.europa.eu/publications/air-quality-in-europe-2016 ([Online; accessed March 1, 2017]) doi: 10.2800/413142

FAO. (2015). *Feeding the cities.* Retrieved from http://www.fao.org/worldfoodsummit/english/fsheets/cities.pdf ([Online; accessed March 23, 2017])

Federal Office for the Environment, Switzerland. (2016). *Glossary of pollutants.* Retrieved from https://www.bafu.admin.ch/bafu/en/home/topics/chemicals/glossary-of-pollutants-overview.html ([Online; accessed February 22, 2017])

Franke, J., Hellsten, A., Schlünzen, H. & Carissimo, B. (2007). Best practice guideline for the CFD simulation of flows in the urban environment. (COST Action 732 Quality Assurance and Improvement of Microscale Meteorological Models)

Franke, J., Hirsch, C., Jensen, A., Krüs, H., Schatzmann, M., Westbury, P., … Wright, N. (2004). Recommendations on the use of CFD in wind engineering. (Proceedings of the International Conference on Urban Wind Engineering and Building Aerodynamics. COST Action C14, Impact of Wind and Storm on City Life Built Environment)

Franzaring, J. H. & Eerden, L. J. M. v. d. (2000). Accumulation of persistent organic pollutants (pops) in plants. *Basic and Applied Ecology*, *1*, 25–30.

Government of the Netherlands. (n.d.). *Situation of ground water.* Retrieved from https://www.government.nl/topics/water-management/contents/water-quality/quality-of-ground-water ([Online; accessed June 14, 2017])

Government of the Netherlands. (2017). *Food safety requirements.* Retrieved from https://www.government.nl/topics/food/contents/food-safety-requirements ([Online; accessed March 23, 2017])

Hargreaves, D. & Wright, N. (2007). On the use of the k– model in commercial cfd software to model the neutral atmospheric boundary layer. *Journal of Wind Engineering and Industrial Aerodynamics*, *95*(5), 355 - 369. Retrieved from http://www.sciencedirect.com/science/article/pii/S016761050600136X doi: http://dx.doi.org/10.1016/j.jweia.2006.08.002

Hazelton, P. & Murphy, B. (2011). *Understanding soils in urban environments.* Earthscan.

Hopkins, F. M., Ehleringer, J. R., Bush, S. E., Duren, R. M., Miller, C. E., Lai, C.-T., … Randerson, J. T. (2016). Mitigation of methane emissions in cities: How new measurements and partnerships can contribute to emissions reduction strategies. *Earth's Future*, *4*, 408-425. doi: 10.1002/2016EF000381

Huang, L., Gong, S. L., Gordon, M., Liggio, J., Staebler, R., Stroud, C. A., … Jia, C. Q. (2014). Aerosol–computational fluid dynamics modeling of ultrafine and black carbon particle emission, dilution, and growth near roadways. *Atmospheric Chemistry and Physics*, *14*(23), 12631–12648. Retrieved from https://www.atmos-chem-phys.net/14/12631/2014/ doi: 10.5194/acp-14-12631-2014

Hulskotte, J., van der Gon, H. D., Visschedijk, A. & Schaap, M. (2007). Brake wear from vehicles as an important source of diffuse copper pollution. *Water Science & Technology*, *56*, 223–231. doi: 10.2166/wst.2007.456

Iammarino, M., Di Taranto, A. & Cristino, M. (2014). Monitoring of nitrites and nitrates levels in leafy vegetables (spinach and lettuce): a contribution to risk assessment. *Journal of the Science of Food and Agriculture*, *94*(4), 773–778. Retrieved from http://dx.doi.org/10.1002/jsfa.6439 doi: 10.1002/jsfa.6439

Janhall, S. (2015). Review on urban vegetation and particle air pollution - deposition and dispersion. *Atmospheric Environment*, *105*, 130-137. doi: 10.1016/j.atmosenv.2015.01.052

Jansma, J. E., Chambers, J., Sabas, E. & Veen, E. (2015). *The Urban Agriculture Circle: A Methodology to Understand the Multi-functionality of Urban Agriculture.* Retrieved from `http://edepot.wur.nl/365985` (Second International Conference on Agriculture in an Urbanizing Society: Reconnecting Agriculture and Food Chains to Societal Needs)

Jimmink, B., ten Broeke, H., Coenen, P., Dröge, R., Geilenkirchen, G., Leekstra, A., ... J. Vonk, D. W. (2014). *Emissions of transboundary air pollutants in the Netherlands 1990-2012.* PBL Netherlands Environmental Assessment Agency. Retrieved from `http://www.pbl.nl/en/publications/` ([Online; accessed March 1, 2017])

Joint FAO/WHO. (1995). *General standards for contaminants and toxins in food and feed.* Codex Alimentarius Commission. Retrieved from `http://www.fao.org/fao-who-codexalimentarius/` ([Revised in 1997, 2006, 2008, 2009. Amended in 2010, 2012, 2013, 2014, 2015.])

Khan, M. S., Zaidi, A., Goel, R. & Musarrat, J. (2011). *Biomanagement of metal-contaminated soils.* Springer. doi: 10.1007/978-94-007-1914-9

Kim, H.-S., Kim, K.-R., Lim, G.-H., Kim, J.-W. & Kim, K.-H. (2015). Influence of airborne dust on the metal concentrations in crop plants cultivated in a rooftop garden in seoul. *Soil Science and Plant Nutrition*, *61*, 88–97. doi: 10.1080/00380768.2015.1028873

Kim, N. D. & Fergusson, J. E. (1994). The concentrations, distribution and sources of cadmium, copper, lead and zinc in the atmosphere of an urban environment. *The Science of the Total Environment*, *144*, 179–189.

Klumpp, A., Ansel, W. & Klumpp, G. (2004). *Urban Air Pollution, Bioindication and Environmental Awarness.* Cuvillier Verlag.

Klumpp, A., Fomin, A., Klumpp, G. & Ansel, W. (2002). *Bioindicators and air quality in european cities.* Verlag Gunter Heimbach.

Lagzi, I., Mészáros, R., Gelybó, G. & Ádám Leelőssy. (2013). *Atmospheric chemistry.* Eötvös Loránd University.

Liati, A., Spiteri, A., Dimopoulos Eggenschwiler, P. & Vogel-Schäuble, N. (2012, 5th Oct). Microscopic investigation of soot and ash particulate matter derived from biofuel and diesel: implications for the reactivity of soot. *Journal of Nanoparticle Research*, *14*(11), 1224. Retrieved from `https://doi.org/10.1007/s11051-012-1224-7` doi: 10.1007/s11051-012-1224-7

Litschke, T. & Kuttler, W. (2008). On the reduction of urban particle concentration by vegetation – a review. *Meteorologische Zeitschrift*, *17*, 229–240. doi: 10.1127/0941-2948/2008/0284

Markert, B., Breure, A. & Zechmeister, H. (2003). *Bioindicators and biomonitors.* Elsevier.

Maurer, K. D., Bohrer, G., Kenny, W. T. & Ivanov, V. Y. (2015). Large-eddy simulations of surface roughness parameter sensitivity to canopy-structure characteristics. *Biogeosciences*, *12*, 2533–2548. doi: 10.5194/bg-12-2533-2015

Meera, V. & Ahammed, M. M. (2006). Water quality of rooftop rainwater harvesting systems: a review. *Journal of Water Supply: Research and Technology - AQUA*, *55*, 257–268.

Meuser, H. (2010). *Contaminated urban soils* (Vol. 18). Springer. doi: 10.1007/978-90-481-9328-8

National Geographic. (2017). *Interactive map.* Retrieved from `http://mapmaker.nationalgeographic.org` ([Online; accessed March 15, 2017])

Nikolova, I., Janssen, S., Vos, P. & Berghmans, P. (2014). Modelling the mixing of size resolved traffic induced and background ultrafine particles from an urban street canyon to adjacent backyards. *Aerosol and Air Quality Research*, *14*, 145–155. doi:

10.4209/aaqr.2013.06.0221

Niu, Z., Zhang, X., Wang, Z. & Ci, Z. (2011). Field controlled experiments of mercury accumulation in crops from air and soil. *Environmental Pollution*, *159*(10), 2684 - 2689. Retrieved from http://www.sciencedirect.com/science/article/pii/S0269749111003162 (Nitrogen Deposition, Critical Loads and Biodiversity) doi: http://dx.doi.org/10.1016/j.envpol.2011.05.029

Pearson, J. & Stewart, G. R. (1993). The deposition of atmospheric ammonia and its effects on plants. *New Phytologist*, *125*, 283–305. doi: 10.1111/j.1469-8137.1993.tb03882.x

Proietti, S., Moscatello, S., Giacomelli, G. A. & Battistelli, A. (2013). Influence of the interaction between light intensity and co2 concentration on productivity and quality of spinach (spinacia oleracea l.) grown in fully controlled environment. *Advances in Space Research*, *52*(6), 1193 - 1200. Retrieved from http://www.sciencedirect.com/science/article/pii/S0273117713003463 doi: http://dx.doi.org/10.1016/j.asr.2013.06.005

Prové, C., Dessein, J. & de Krom, M. (n.d.). taking context into account in urban agriculture governance: Case studies of warsaw (poland) and ghent (belgium).

Pulliam, T. H. & Zingg, D. W. (2014). *Fundamental algorithms in computational fluid dynamics.* Springer.

Raub, J. (2004). *Carbon monoxide (second edition).* US EPA and WHO. Retrieved from http://apps.who.int/iris/bitstream/10665/42180/1/WHO_EHC_213.pdf ([Online; accessed May 2, 2017])

Ren, Z. & Stewart, J. (2003). Simulating air flow and temperature distribution inside buildings using a modified version of comis with sub-zonal divisions. *Energy and Buildings*, *35*(3), 257 - 271. Retrieved from http://www.sciencedirect.com/science/article/pii/S0378778802000877 doi: http://dx.doi.org/10.1016/S0378-7788(02)00087-7

Robinson, E. & Robbins, R. C. (2012). Gaseous nitrogen compound pollutants from urban and natural sources. *Journal of the Air Pollution Control Association*, *20*, 303–306. doi: 10.1080/00022470.1970.10469405

Ruellan, S. & Cachier, H. (2001). Characterisation of fresh particulate vehicular exhausts near a paris high flow road. *Atmospheric Environment*, *35*(2), 453 - 468. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231000001102 doi: http://dx.doi.org/10.1016/S1352-2310(00)00110-2

Sabatino, S. D., Buccolieri, R., Pulvirenti, B. & Britter, R. E. (2008, 1st Sep). Flow and pollutant dispersion in street canyons using fluent and adms-urban. *Environmental Modeling & Assessment*, *13*(3), 369–381. Retrieved from https://doi.org/10.1007/s10666-007-9106-6 doi: 10.1007/s10666-007-9106-6

Schultz, C. (2013). Chamber measurements find plants are potentially important methane sink. *Eos, Transactions American Geophysical Union*, *94*(5), 60–60. Retrieved from http://dx.doi.org/10.1002/2013EO050013 doi: 10.1002/2013EO050013

Shen, H. (2016). *Polycyclic aromatic hydrocarbons - their global atmospheric emissions, transport, and lung cancer risk.* Springer.

Simonich, S. L. & Hites, R. A. (1994). Importance of vegetation in removing polycyclic aromatic hydrocarbons from the atmosphere. *Natures*, *370*, 49–51. doi: 10.1038/370049a0

Singh, A., Sharma, R. K., Agrawal, M. & Marshall, F. M. (2010). Health risk assessment of heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of india. *Food and Chemical Toxicology*, *48*(2), 611–619. doi: 10.1016/j.fct.2009.11.041

Steel, C. (2008). *Hungry city: how food shapes our lives.* Chatto & Windus.

Steyaert, L. T. & Knox, R. G. (2008). Reconstructed historical land cover and biophysical parameters for studies of land-atmosphere interactions within the eastern united states.

Journal of Geophysical Research: Atmospheres, *113*(D2), n/a–n/a. Retrieved from http://dx.doi.org/10.1029/2006JD008277 (D02101) doi: 10.1029/2006JD008277

Stogiannidis, E. & Laane, R. (2014). Source characterization of polycyclic aromatic hydrocarbons by using their molecular indices: An overview of possibilities. *Reviews of Environmental Contamination and Toxicology*, *234*, 49–133. doi: 10.1007/978-3-319-10638-0_2

Sundqvist, E., Crill, P., Mölder, M., Vestin, P. & Lindroth, A. (2012). Atmospheric methane removal by boreal plants. *Geophysical Research Letters*, *39*(21). Retrieved from http://dx.doi.org/10.1029/2012GL053592 (L21806) doi: 10.1029/2012GL053592

Säumel, I., Kotsyuk, I., Hölscher, M., Lenkereit, C., Weber, F. & Kowarik, I. (2012). How healthy is urban horticulture in high traffic areas? Trace metal concentrations in vegetable crops from plantings within inner city neighbourhoods in Berlin, Germany. *Environmental Pollution*, *165*, 124–132. doi: 10.1016/j.envpol.2012.02.019

Thaker, P. & Gokhale, S. (2016). The impact of traffic-flow patterns on air quality in urban street canyons. *Environmental Pollution*, *208*, 161 - 169. Retrieved from http://www.sciencedirect.com/science/article/pii/S026974911530052X (Special Issue: Urban Health and Wellbeing) doi: http://dx.doi.org/10.1016/j.envpol.2015.09.004

Tong, Z., Wang, Y., Patel, M., Kinney, P., Chrillrud, S. & Zhang, K. M. (2012, 01). Modeling spatial variations of black carbon particles in an urban highway-buildings environment. *Environmental science & technology*, *46*(1), 312–319. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3258341/ doi: 10.1021/es201938v

Tucker, P. G. (2011). *Case Studies in Environmental Medicine (CSEM) Cadmium Toxicity.* ATSDR Agency for Toxic Substances and Disease Registry. Retrieved from https://www.atsdr.cdc.gov/csem/cadmium/docs/cadmium.pdf ([Online; accessed April 24, 2017])

Uhrner, U., von Löwis, S., Vehkamäki, H., Wehner, B., Bräsel, S., Hermann, M., ... Wiedensohler, A. (2007). Dilution and aerosol dynamics within a diesel car exhaust plume—cfd simulations of on-road measurement conditions. *Atmospheric Environment*, *41*(35), 7440 - 7461. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231007005006 doi: http://dx.doi.org/10.1016/j.atmosenv.2007.05.057

US Department of Health and Human Services. (1999). *Toxicological profile for mercury.* ATSDR Agency for Toxic Substances and Disease Registry. Retrieved from https://www.atsdr.cdc.gov/toxprofiles/tp46.pdf ([Online; accessed April 25, 2017])

U.S. Environmental Protection Agency. (2005). *Review of the National Ambient Air Quality Standards for Particulate Matter: Policy Assessment of Scientific and Technical Information, OAQPS Staff Paper.* Retrieved from https://www3.epa.gov/ttn/naaqs/standards/pm/data/pmstaffpaper_20051221.pdf ([Online; accessed July 14, 2017])

van der Schans, J. W. (2010). Urban Agriculture in the Netherlands. *UA Magazine*, *24*, 40–42.

van der Voet, E., Guinée, J. B. & Udo de Haes, H. A. (1998). *Metals in the Netherlands: a problem solved?* Leiden University: Centre of Environmental Science. (Paper for the IVEM workshop Natural Resource Modelling)

van Dijk, C., van Doorn, W. & van Alfen, B. (2015). Long term plant biomonitoring in the vicinity of waste incinerators in the Netherlands. *Chemosphere*, *122*, 45–51. doi: 10.1016/j.chemosphere.2014.11.002

van Gestel, C. & van Brummelen, T. (1995). Incorporation of the biomarker concept in ecotoxicology calls for a redefinition of terms. *Ecotoxicology*, *5*, 217–225.

Veen, E. J. (2015). *Community gardens in urban areas: A critical reflection on the extent to which they strengthen social cohesion and provide alternative food* (Unpublished doctoral dissertation). Wageningen University.

Vewin. (2017). *Dutch water sector.* Retrieved from http://www.vewin.nl/ ([Online; accessed May 18, 2017])

Voltaggio, M., Spadoni, M., Carloni, S. & Guglietta, D. (2016). 212pb as tracer for pm deposition on urban vegetation. *Science of The Total Environment*, *569*, 9 - 15. Retrieved from http://www.sciencedirect.com/science/article/pii/S0048969716312190 doi: http://dx.doi.org/10.1016/j.scitotenv.2016.06.051

Wang, Q., Liu, M., Li, Y., Liu, Y., Li, S. & Ge, R. (2016). Dry and wet deposition of polycyclic aromatic hydrocarbons and comparison with typical media in urban system of shanghai, china. *Atmospheric Environment*, *144*, 175 - 181. Retrieved from http://www.sciencedirect.com/science/article/pii/S1352231016306859 doi: http://dx.doi.org/10.1016/j.atmosenv.2016.08.079

Wang, S., Nan, J., Shi, C., Fu, Q., Gao, S., Wang, D., ... Zhou, B. (2015). Atmospheric ammonia and its impacts on regional air quality over the megacity of shanghai, china. *Scientific Reports*, *5*. doi: 10.1038/srep15842

Weinstock, B. & Niki, H. (1972). Carbon monoxide balance in nature. *Science*, *176*, 290-292. doi: 10.1126/science.176.4032.290

World Health Organization. (n.d.). *The lexicon Tolerable Daily Intake (TDI).* Retrieved from http://apps.who.int/thelexicon/entry.php ([Online; accessed June 22, 2017])

World Health Organization. (2003). *Health aspects with particulate matter, ozone and nitrogen dioxide.* Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0005/112199/E79097.pdf ([Online; accessed February 23, 2017])

World Health Organization. (2016). *Dioxins and their effects on human health.* Retrieved from http://www.who.int/mediacentre/factsheets/fs225/en/ ([Online; accessed February 28, 2017])

Xue, F. & Li, X. (2017). The impact of roadside trees on traffic released pm10 in urban street canyon: Aerodynamic and deposition effects. *Sustainable Cities and Society*, *30*, 195–204. Retrieved from http://www.sciencedirect.com/science/article/pii/S2210670716304528 doi: http://dx.doi.org/10.1016/j.scs.2017.02.001

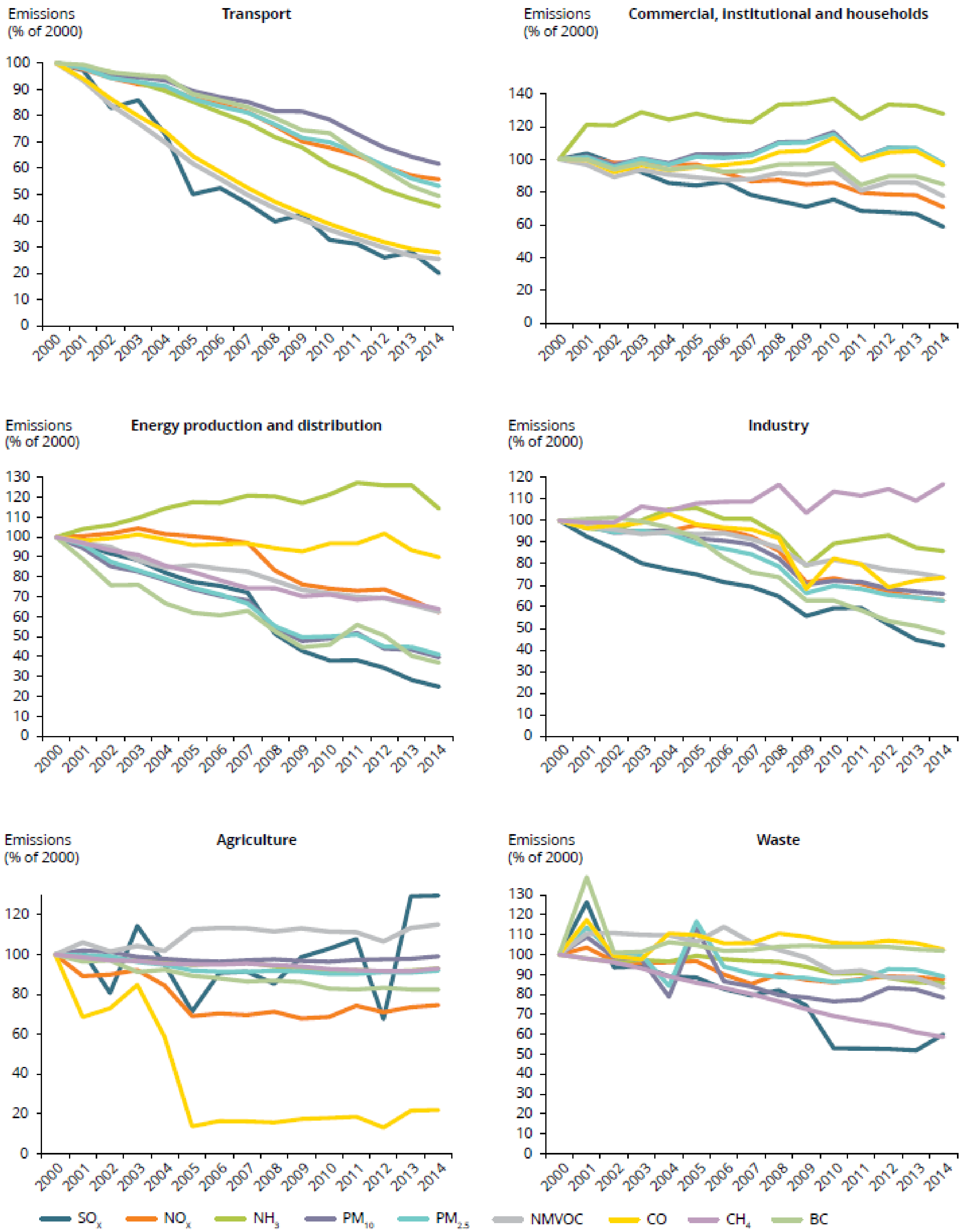
Zasada, I. (2011). Multifunctional peri-urban agriculture—a review of societal demands and the provision of goods and services by farming. *Land Use Policy*, *28*, 639–648. doi: 10.1016/j.landusepol.2011.01.008

Zhuang, P., McBride, M. B., Xia, H., Li, N. & Li, Z. (2009). Health risk from heavy metals via consumption of food crops in the vicinity of Dabaoshan mine, South China. *Science of The Total Environment*, *407*, 1551–1561. doi: 10.1016/j.scitotenv.2008.10.061

Index

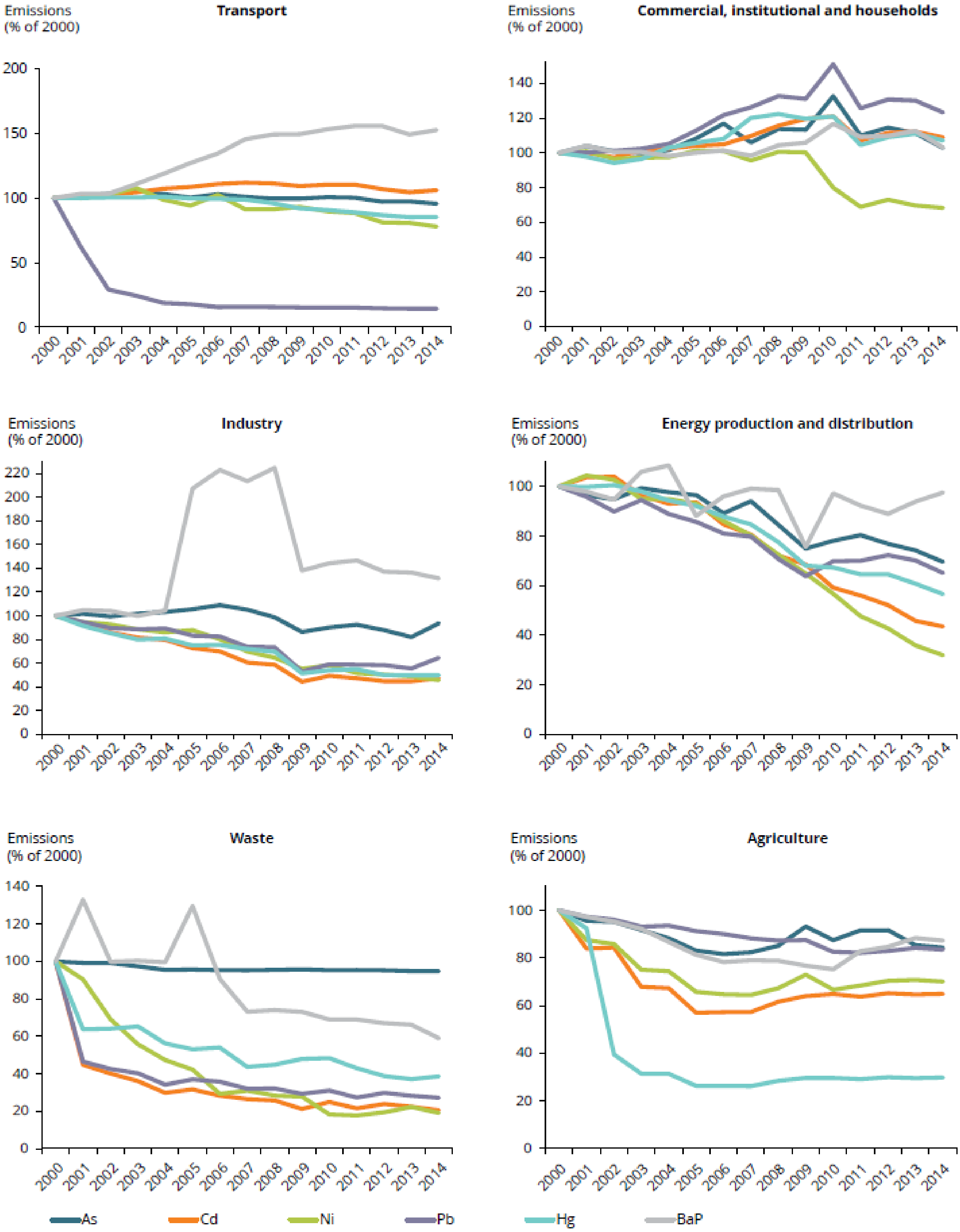
Appendices

A Air pollutant emissions from diverse sources in the EU



(a)

Figure 11 – Emissions from the main source sectors in 28 countries of the European Union (European Environment Agency, 2016)



(b) Heavy metals

Figure 11 – Emissions from the main source sectors in 28 countries of the European Union (European Environment Agency, 2016)

B Interviews

In this section, an overview of the main questions that were tackled during the interviews is given. The first topic was about the spatial planning, therefore, targeting the work of the respondents. It was about how to plan a city with green spaces and especially green initiatives. Some questions on the number of UA initiatives and the municipality's supports were also asked for the sake of getting an overall idea on the development of the municipality. The second part assessed the awareness of the policy makers on the limits that regulate contaminants' concentrations in food. If they were sensible about these, do they know how often the limits are met? It led to the food security topic, about the potential and risks of UA. If UA could contribute to food security by easing the access to healthy food, we may ingest harmful compounds while consuming urban products. Therefore, the respondents were asked about the differences of pollutant levels between RA and UA. Last but not least, the citizens and consumers' concern was discussed. It intends to see if some actions were undertaken to fight these issues.

The questions are summarised as follows:

1. Spatial planning
    - How do you define an UA initiative? What type of initiatives is present in your city?
    - How do you define the urban boundaries of the city? Do you consider peri-urban as part of UA?
    - Do you take in consideration air pollution issues when it concerns the location of UA?
    - What are the objectives of the municipality to support UA initiatives?
    - Do they evaluate their objectives? Success, no effect, costly...
    - Are the results of UA for self-provision or also supplying markets/restaurants, etc? What is the economic value of UA?
2. Regulations and limits
    - Do you know about the regulations of heavy metals, PAHs and other contaminants in foodstuff?
    - Do you know if these limits are often met?
3. Food security
    - Do you know about the risks of ingesting high concentrations of heavy metals?
    - Are you aware of the differences of concentrations of pollutants in vegetables from rural and urban areas?
    - Do you consider urban farming as a way to improve food security?
4. Citizens and consumers concern
    - Does the population ask about these risks? Farmers?
    - If so, do they try to fight these issues? How?

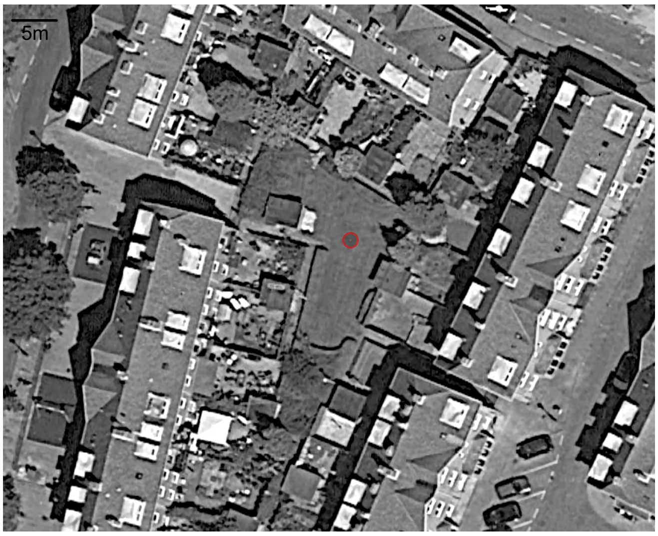
C Bio-monitoring sites in Amsterdam

(a)

(b)

Figure 12 – Voedseltuinen IJplein

(a)



(b)

Figure 13 – Ranonkelkade garden

(a)

(b)

Figure 14 – Suzanne's allotment in Sloterland

D Modelling with Ansys Fluent v18.0 - Geometry and boundary conditions

Table 7 – Geometric characteristics of the rural domain

Geometry	
Height of the domain	100 m
Length of the domain	200 m
Max Face Size	1.0 m
Total number of elements	20,000
Total number of nodes	20,301

Table 8 – Boundary conditions of the rural domain

Boundary	Boundary conditions
Air inlet	Velocity (normal to boundary) = 4 m/s T = 288.16 K
	DPM as inert particle Mass flow rate = 1.0E-03 kg/s Particle diameter: d_p = 10 μm T = 288.16 K
Outlet	Pressure outlet
Gardens	$C_s = 1$ $K_s = 0.3$
Wall	No slip boundary conditions
Top (geostrophic wind)	Symmetry

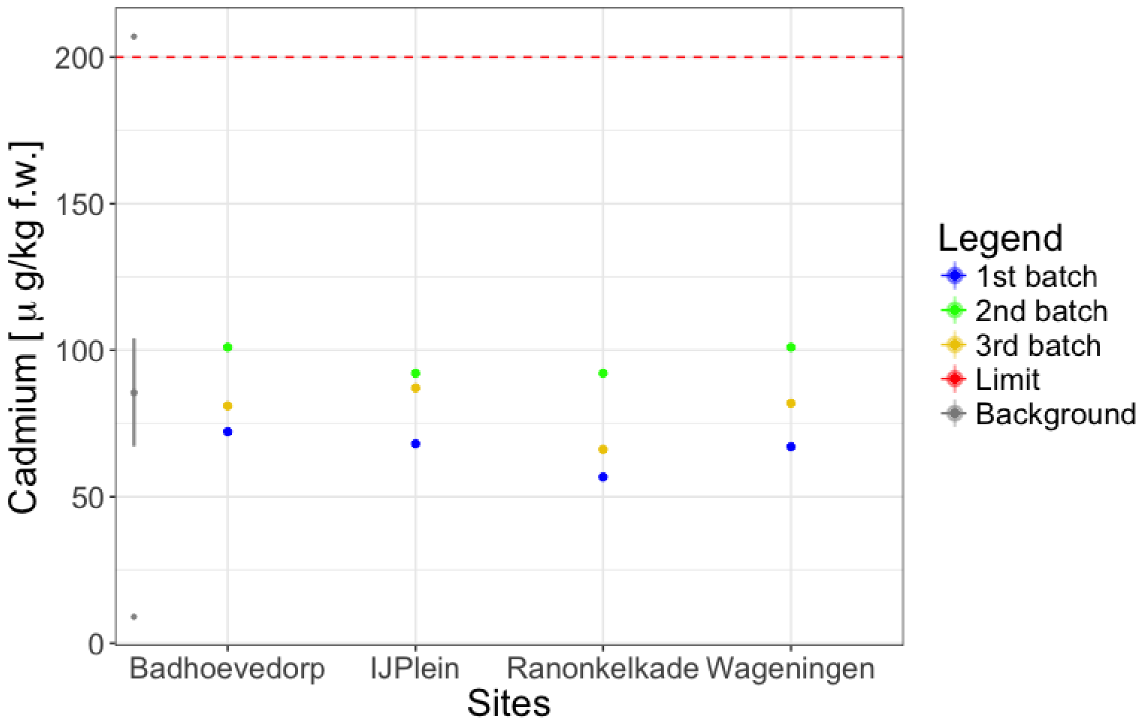
E Results of the bio-monitoring

Table 9 – Heavy metals and Nitrate in spinach [µg/kg f.w.]

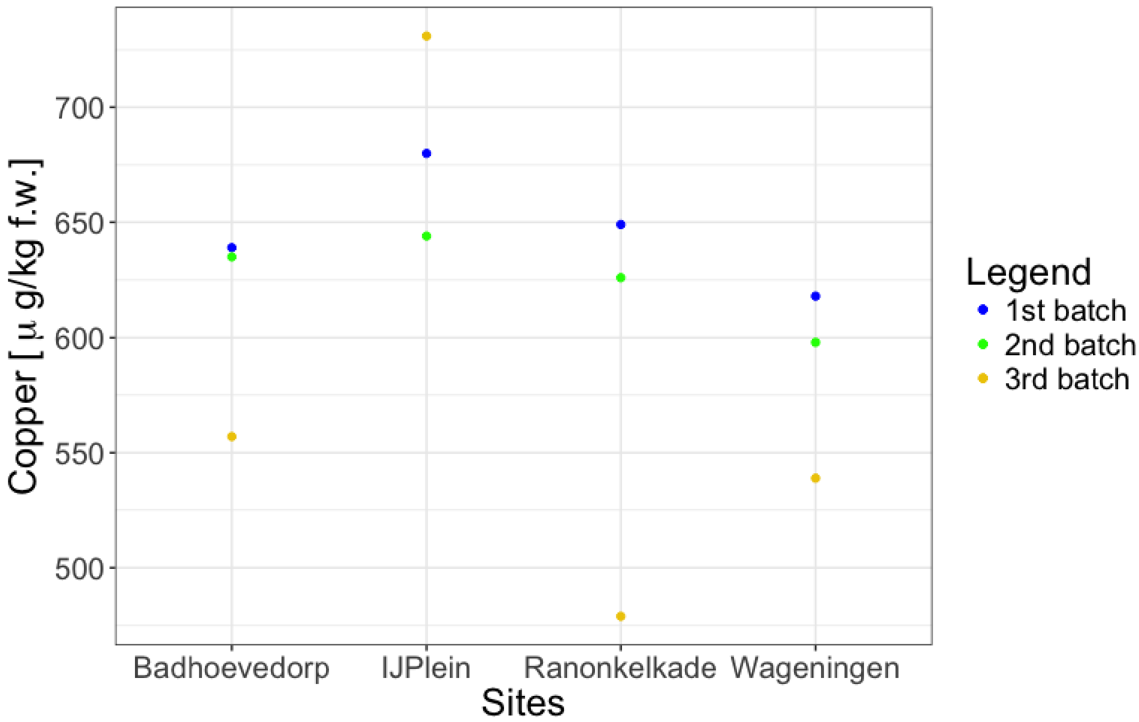
Date	Name	Badhoevedorp	IJPlein	Ranonkelkade	Wageningen
Week 19 - 2017	Cadmium	7.21E+01	6.80E+01	5.67E+01	6.70E+01
	Copper	6.39E+02	6.80E+02	6.49E+02	6.18E+02
	Mercury	1.44E+00	1.75E+00	1.44E+00	1.44E+00
	Lead	2.58E+01	3.61E+01	7.62E+01	2.27E+01
	Nitrate	8.24E+05	7.42E+05	6.08E+05	9.17E+05
Week 23 - 2017	Cadmium	1.01E+02	9.20E+01	9.20E+01	1.01E+02
	Copper	6.35E+02	6.44E+02	6.26E+02	5.98E+02
	Mercury	1.10E+00	1.20E+00	9.20E-01	1.10E+00
	Lead	2.12E+01	3.96E+01	4.42E+01	2.58E+01
	Nitrate	1.93E+06	2.21E+06	2.67E+06	2.48E+06
Week 28 - 2017	Cadmium	8.09E+01	8.70E+01	6.61E+01	8.18E+01
	Copper	5.57E+02	7.31E+02	4.79E+02	5.39E+02
	Mercury	1.13E+00	1.31E+00	8.70E-01	1.31E+00
	Lead	1.83E+01	2.96E+01	2.35E+01	1.83E+01
	Nitrate	2.52E+05	1.74E+05	3.65E+05	3.83E+05

Table 10 – PAHs in spinach [μg/kg d.w.], < indicates that the concentrations are below the detection limit

Date	Name	Badhoevedorp	IJPlein	Ranonkelkade	Wageningen
Week 19 - 2017	Acenaphthene	9.85E-01	< 9.15E-01	9.25E-01	1.03E+00
	Acenaphthylene	< 8.11E-01	< 8.15E-01	< 6.41E-01	< 7.29E-01
	Anthracene	< 8.11E-01	< 8.15E-01	6.41E-01	< 7.29E-01
	Benzo(a)anthracene	1.67E+00	1.25E+00	2.45E+00	9.64E-01
	Benzo(b/j)fluoranthene	3.05E+00	2.49E+00	4.67E+00	1.72E+00
	Benzo(ghi)perylene	2.13E+00	1.60E+00	1.91E+00	7.69E-01
	Benzo(a)pyrene	1.33E+00	< 8.15E-01	1.69E+00	< 7.29E-01
	Benzo-(k)-fluoranthene	< 8.11E-01	< 8.15E-01	1.29E+00	< 7.29E-01
	Chrysene	3.33E+00	2.34E+00	4.50E+00	1.86E+00
	Dibenzo(ah)anthracene	1.66E+00	1.69E+00	2.30E+00	1.99E+00
	Fluoranthene	1.26E+01	9.99E+00	1.72E+01	1.22E+01
	Fluorene	1.88E+00	1.68E+00	1.66E+00	1.90E+00
	Indeno(123cd)pyrene	2.06E+00	1.81E+00	2.11E+00	1.04E+00
	Naphthalene	3.49E+00	3.45E+00	2.85E+00	2.53E+00
	Phenanthrene	1.88E+01	1.37E+01	1.74E+01	1.91E+01
	Pyrene	6.14E+00	4.56E+00	8.09E+00	4.84E+00
	Tot 16 EPA-PAH excl LOQ	5.90E+01	4.45E+01	6.98E+01	5.00E+01
	Tot 16 EPA-PAH incl LOQ	6.15E+01	4.86E+01	7.04E+01	5.24E+01
Week 23 - 2017	Acenaphthene	1.30E+00	1.41E+00	1.72E+00	1.08E+00
	Acenaphthylene	< 7.94E-01	< 7.92E-01	< 7.80E-01	< 7.95E-01
	Anthracene	< 7.94E-01	< 7.92E-01	< 7.80E-01	< 7.95E-01
	Benzo(a)anthracene	7.94E-01	1.49E+00	1.49E+00	1.03E+00
	Benzo(b/j)fluoranthene	2.17E+00	3.25E+00	3.28E+00	2.44E+00
	Benzo(ghi)perylene	1.05E+00	1.77E+00	2.00E+00	1.33E+00
	Benzo(a)pyrene	1.13E+00	1.65E+00	1.65E+00	1.37E+00
	Benzo-(k)-fluoranthene	8.64E-01	1.17E+00	1.09E+00	9.96E-01
	Chrysene	1.64E+00	3.03E+00	3.20E+00	1.44E+00
	Dibenzo(ah)anthracene	< 7.94E-01	< 7.92E-01	< 7.80E-01	< 7.95E-01
	Fluoranthene	1.68E+01	1.75E+01	1.77E+01	1.34E+01
	Fluorene	7.84E+00	7.05E+00	5.26E+00	4.26E+00
	Indeno(123cd)pyrene	1.16E+00	1.72E+00	1.84E+00	1.37E+00
	Naphthalene	5.66E+00	6.92E+00	6.29E+00	6.46E+00
	Phenanthrene	3.43E+01	3.39E+01	3.21E+01	3.13E+01
	Pyrene	6.07E+00	8.01E+00	7.68E+00	5.53E+00
	Tot 16 EPA-PAH excl LOQ	8.00E+01	8.89E+01	8.53E+01	7.20E+01
	Tot 16 EPA-PAH incl LOQ	8.32E+01	9.13E+01	8.76E+01	7.44E+01
Week 28 - 2017	Acenaphthene	< 8.06E-01	8.61E-01	8.74E-01	1.11E+00
	Acenaphthylene	< 8.06E-01	< 7.83E-01	< 7.87E-01	< 7.58E-01
	Anthracene	< 8.06E-01	< 7.83E-01	< 7.87E-01	< 7.58E-01
	Benzo(a)anthracene	< 8.06E-01	< 7.83E-01	< 7.87E-01	< 7.58E-01
	Benzo(b/j)fluoranthene	1.28E+00	1.38E+00	1.65E+00	1.03E+00
	Benzo(ghi)perylene	1.16E+00	1.05E+00	7.93E-01	< 7.58E-01
	Benzo(a)pyrene	< 8.06E-01	< 7.83E-01	< 7.87E-01	< 7.58E-01
	Benzo-(k)-fluoranthene	< 8.06E-01	< 7.83E-01	< 7.87E-01	< 7.58E-01
	Chrysene	8.98E-01	2.16E+00	2.26E+00	7.65E-01
	Dibenzo(ah)anthracene	< 8.06E-01	< 7.83E-01	< 7.87E-01	< 7.58E-01
	Fluoranthene	8.98E+00	1.04E+01	1.13E+01	1.08E+01
	Fluorene	1.94E+00	2.87E+00	1.88E+00	2.40E+00
	Indeno(123cd)pyrene	< 8.06E-01	< 7.83E-01	< 7.87E-01	< 7.58E-01
	Naphthalene	< 3.96E-00	< 3.83E-00	< 3.86E-00	< 3.72E-00
	Phenanthrene	1.31E+01	1.52E+01	1.37E+01	1.75E+01
	Pyrene	3.34E+00	5.16E+00	5.09E+00	3.93E+00
	Tot 16 EPA-PAH excl LOQ	3.07E+01	3.91E+01	3.75E+01	3.75E+01
	Tot 16 EPA-PAH incl LOQ	4.11E+01	4.84E+01	4.69E+01	4.73E+01

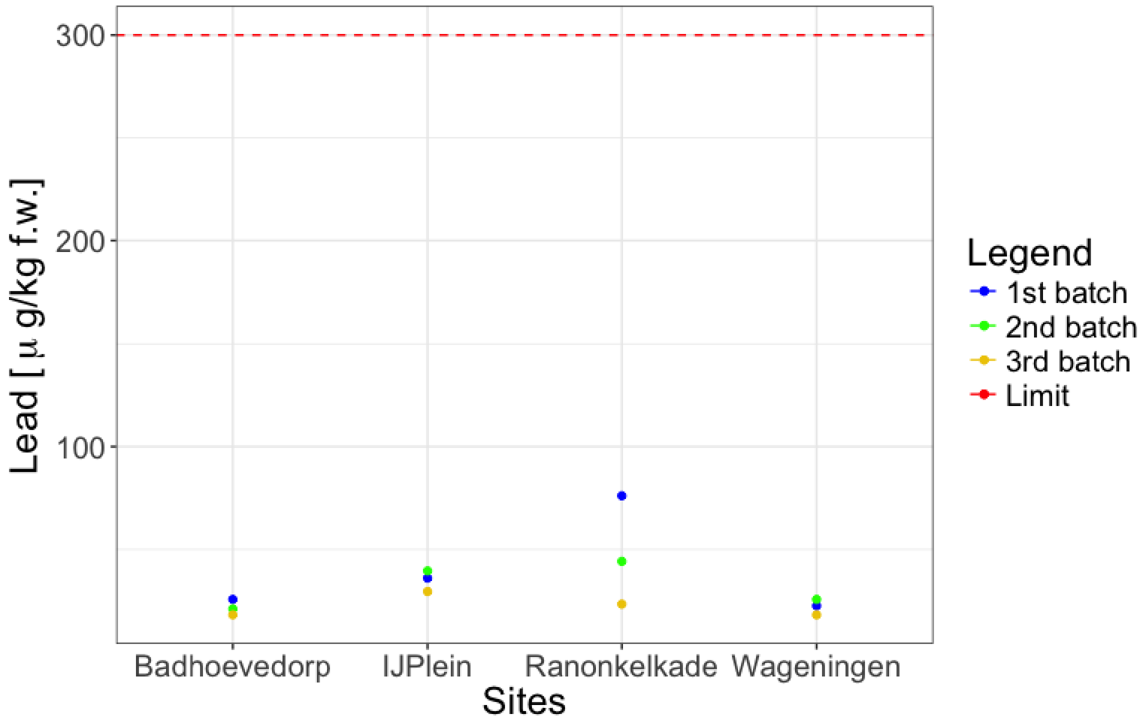


(a)

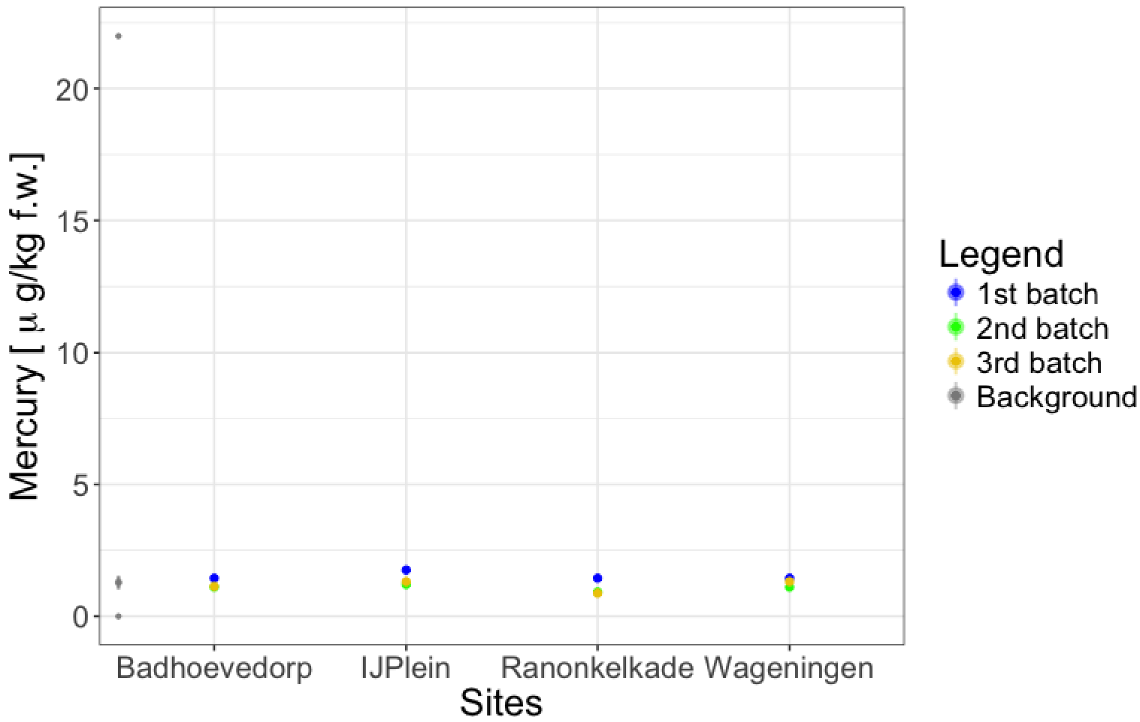


(b)

Figure 15 – Heavy metals' levels for the three period. The middle grey dot corresponds to the median concentration observed for the previous ten years (2006-2016) in rural Netherlands (van Dijk et al., 2015). The bars show the limits of the first and third quartile, the dots are the minimum and maximum value observed over the period. The red-dashed line indicates the legal limit. It is given only for a few heavy metals.

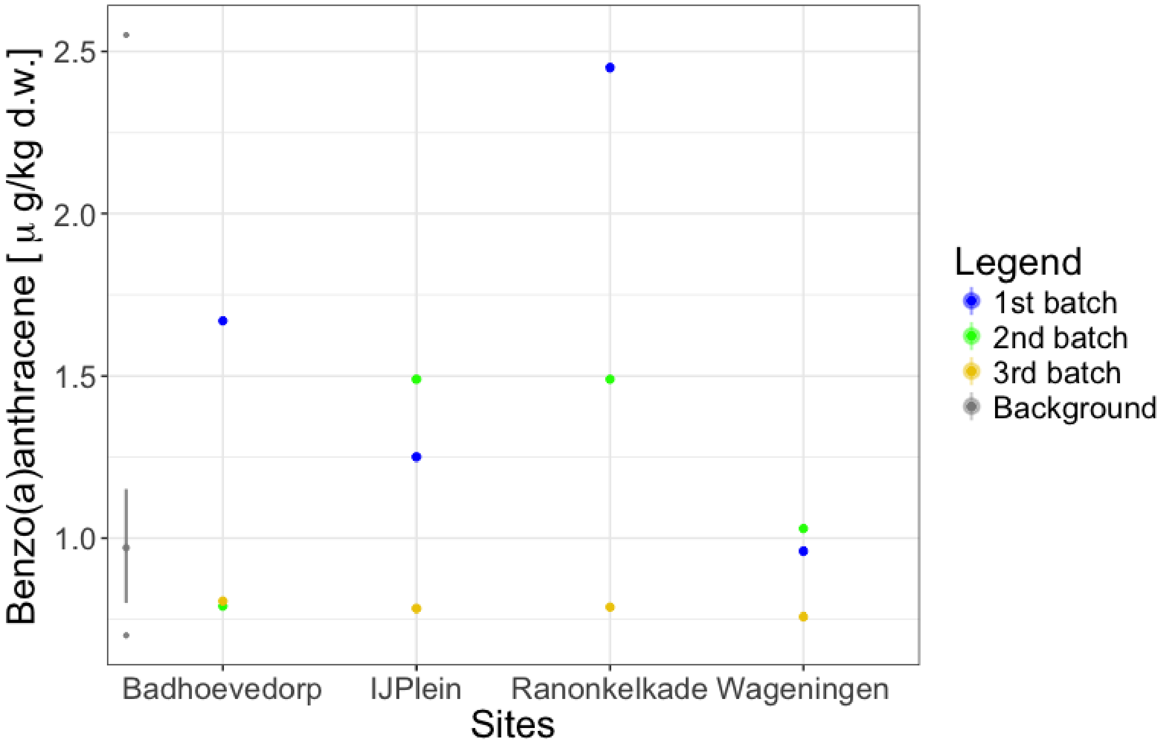


(c)

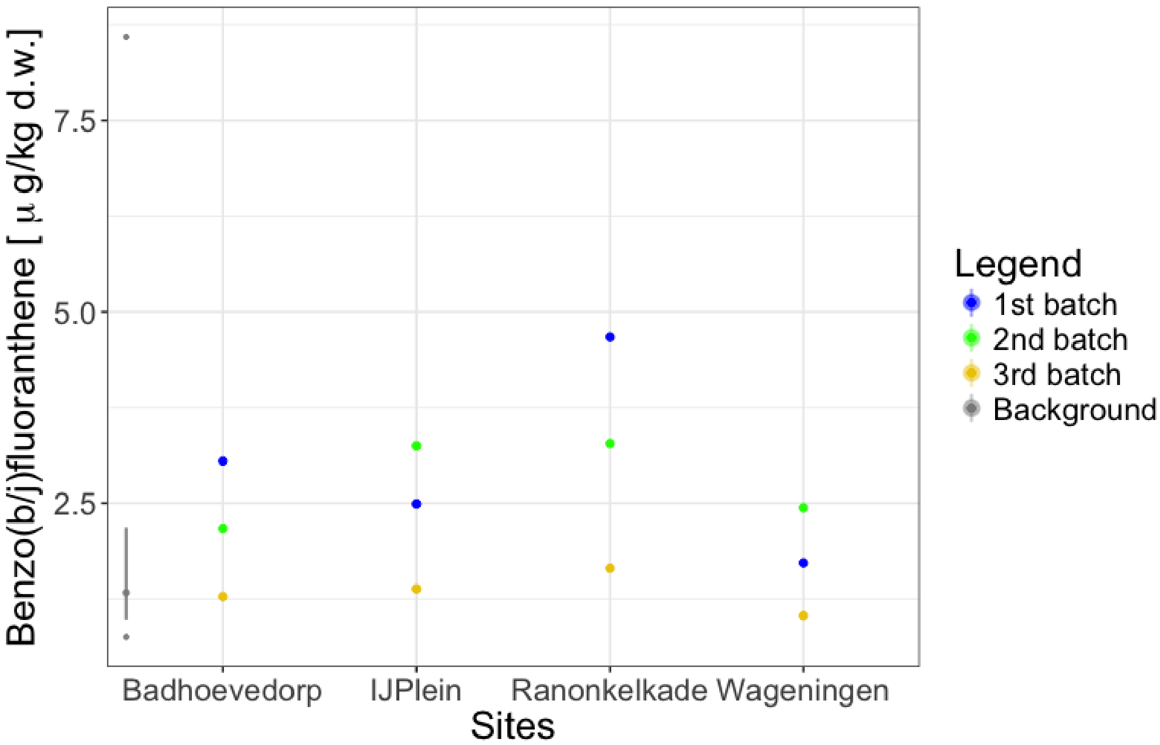


(d)

Figure 15 – Heavy metals' levels for the three period. The middle grey dot corresponds to the median concentration observed for the previous ten years (2006-2016) in rural Netherlands (van Dijk et al., 2015). The bars show the limits of the first and third quartile, the dots are the minimum and maximum value observed over the period. The red-dashed line indicates the legal limit. It is given only for a few heavy metals.

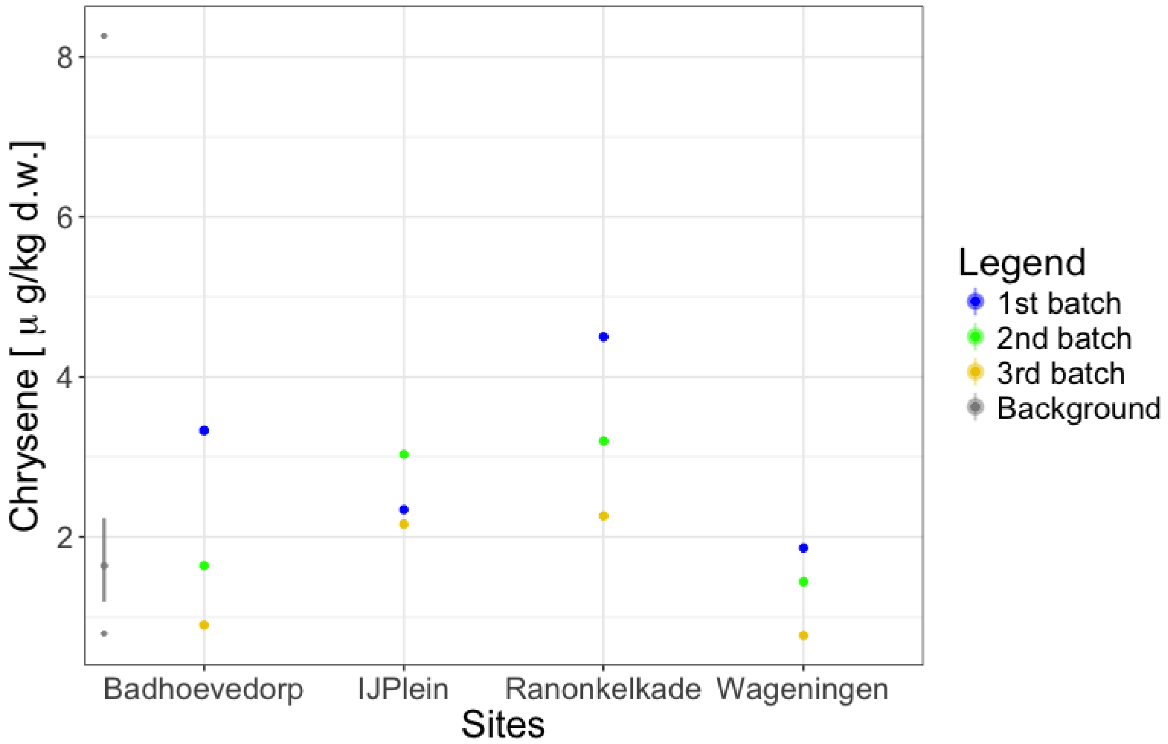


(a)

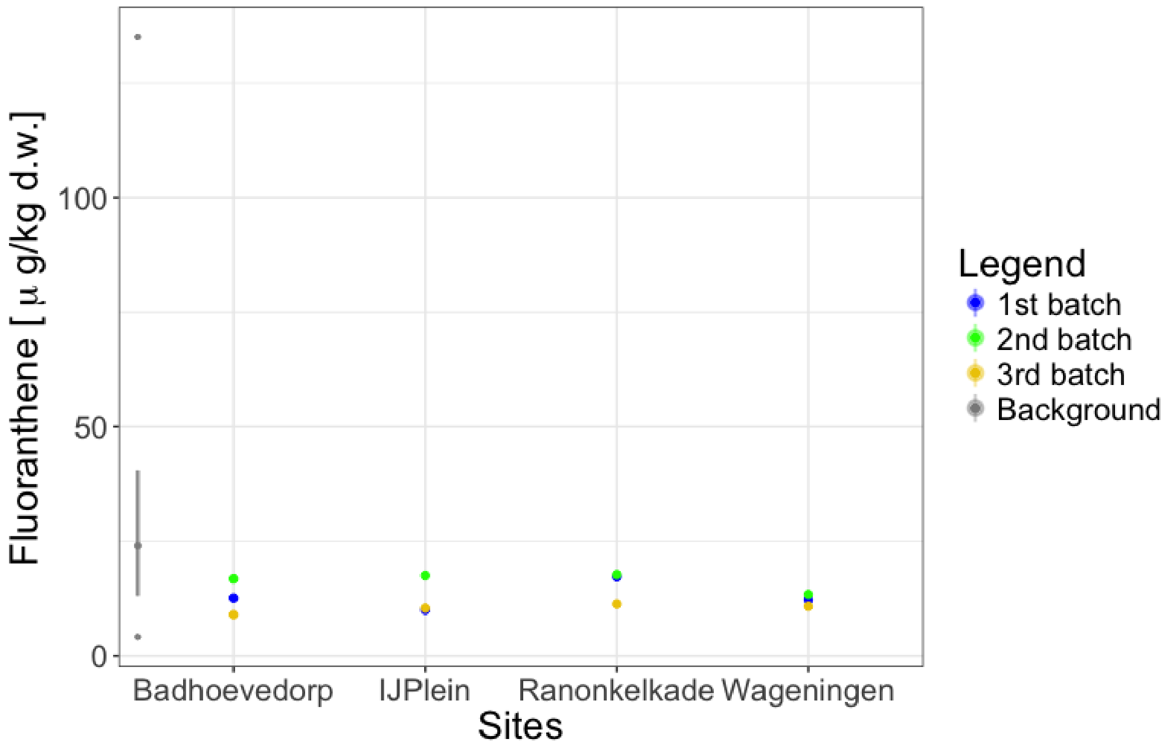


(b)

Figure 16 – PAHs' levels for the three period. The middle grey dot corresponds to the median concentration observed for the previous ten years (2006-2016) in rural Netherlands (van Dijk et al., 2015). The bars show the limits of the first and third quartile, the dots are the minimum and maximum value observed over the period.

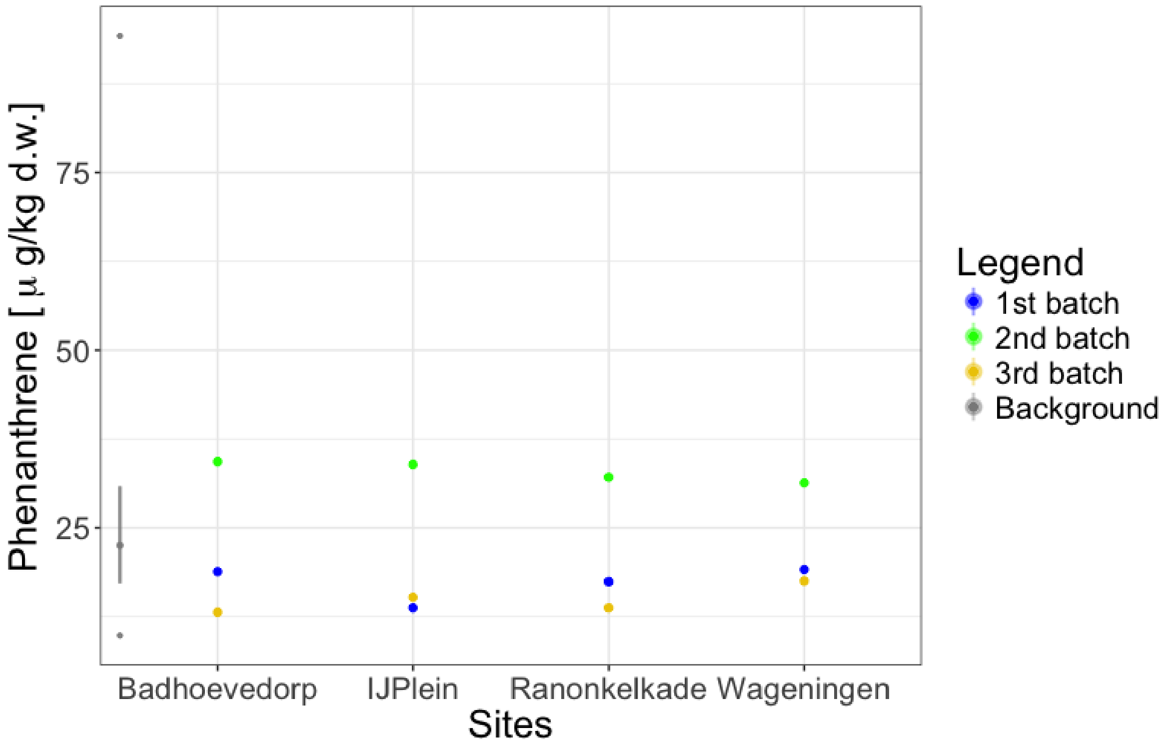


(c)

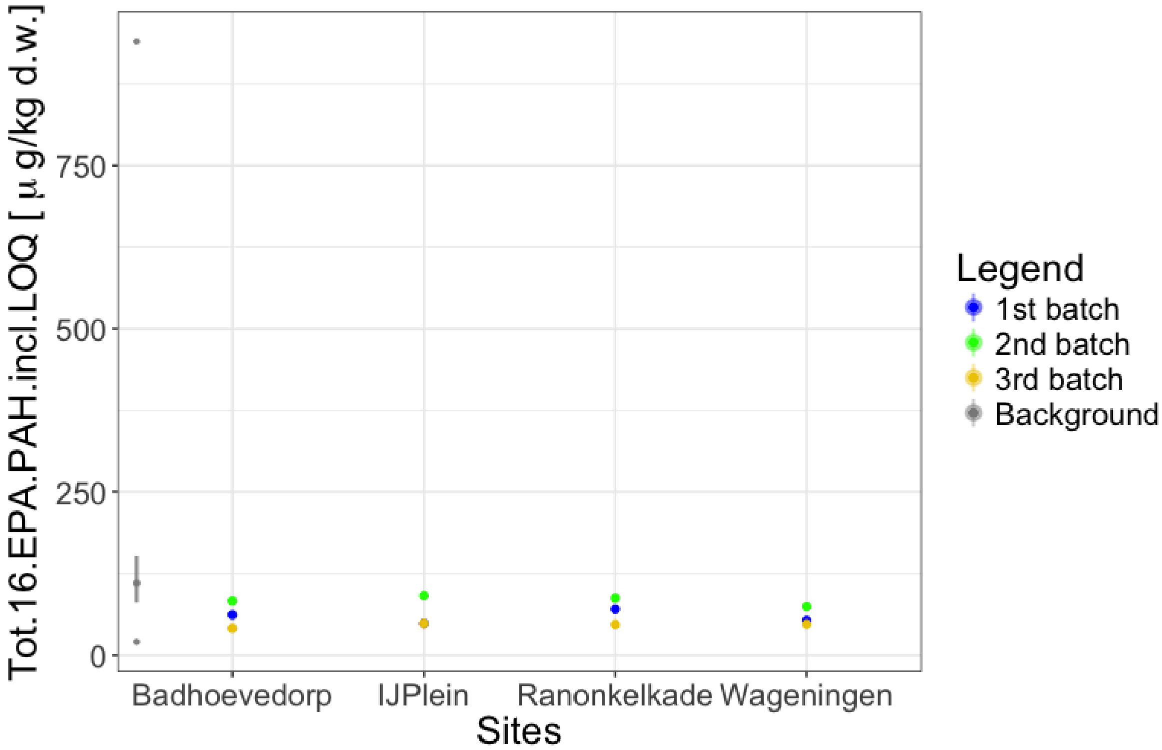


(d)

Figure 16 – PAHs' levels for the three period. The middle grey dot corresponds to the median concentration observed for the previous ten years (2006-2016) in rural Netherlands (van Dijk et al., 2015). The bars show the limits of the first and third quartile, the dots are the minimum and maximum value observed over the period.



(e)



(f)

Figure 16 – PAHs' levels for the three period. The middle grey dot corresponds to the median concentration observed for the previous ten years (2006-2016) in rural Netherlands (van Dijk et al., 2015). The bars show the limits of the first and third quartile, the dots are the minimum and maximum value observed over the period.

F Results of the modelling for the rural design

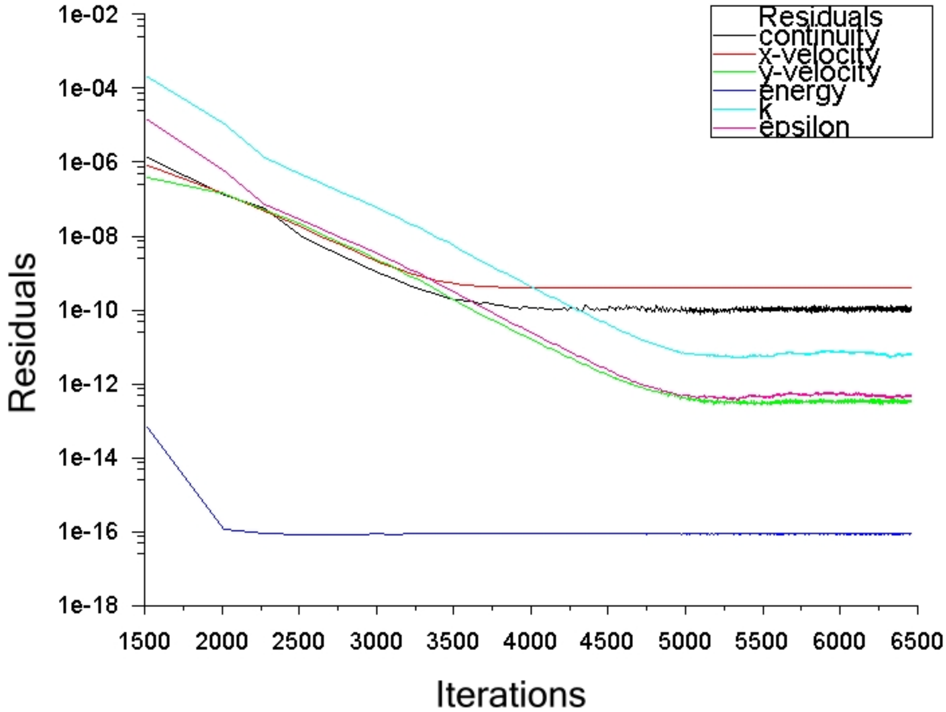
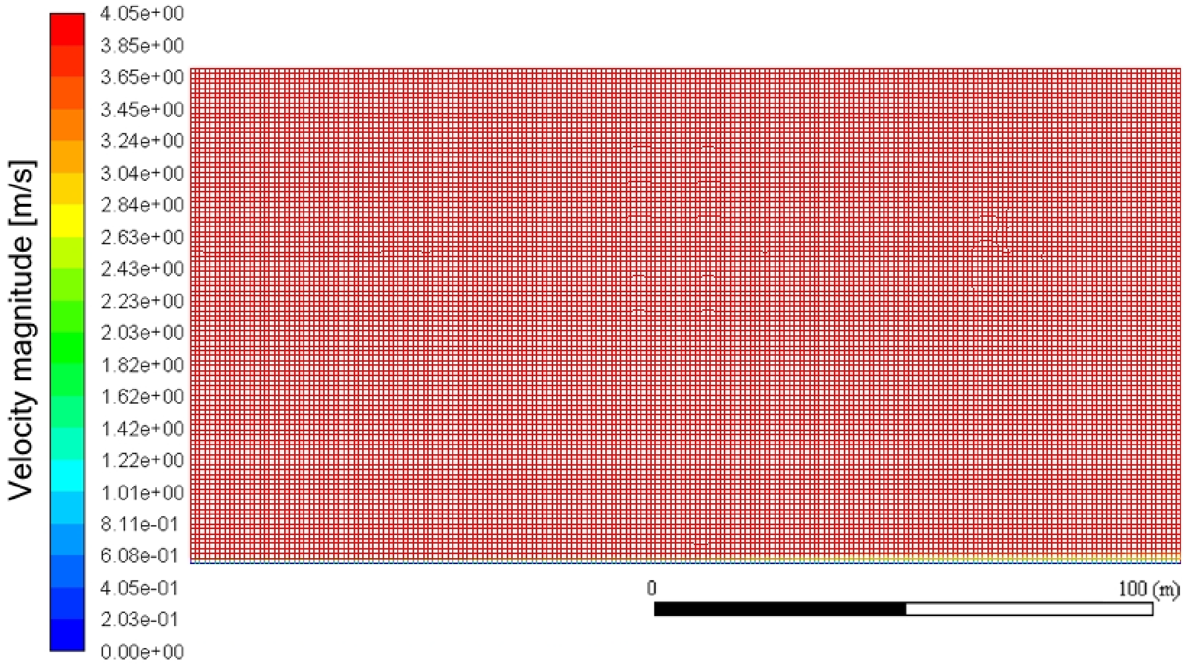
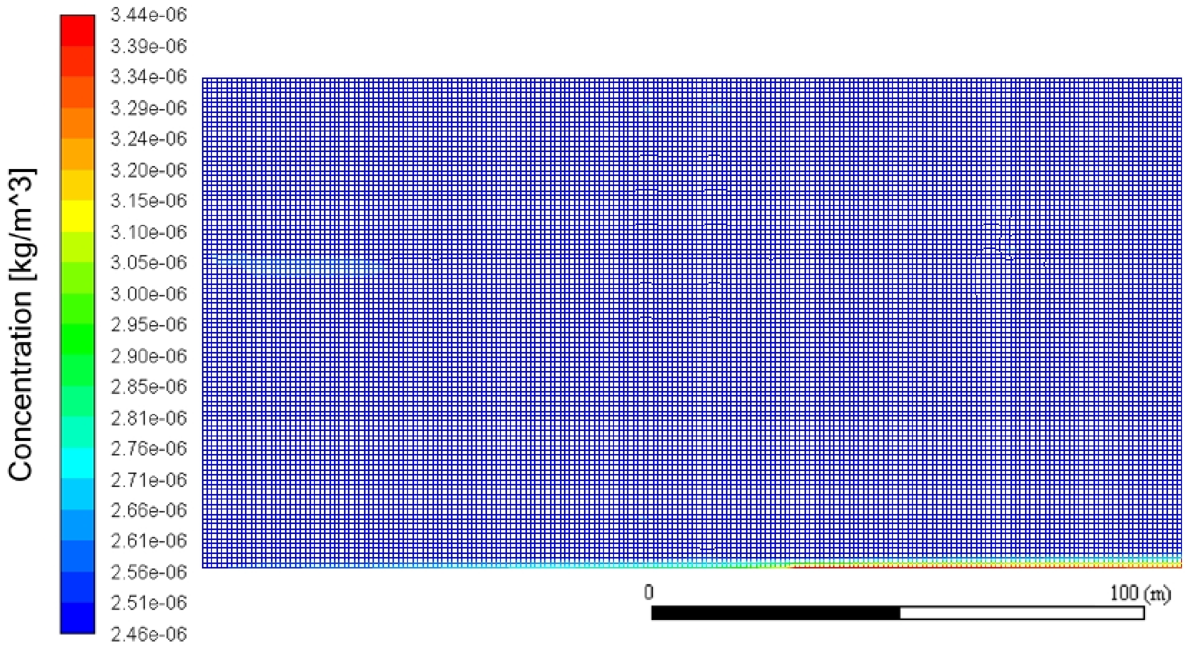


Figure 17 – Residuals after 6,500 iterations for the rural design (logarithmic scale on the Y-axis)

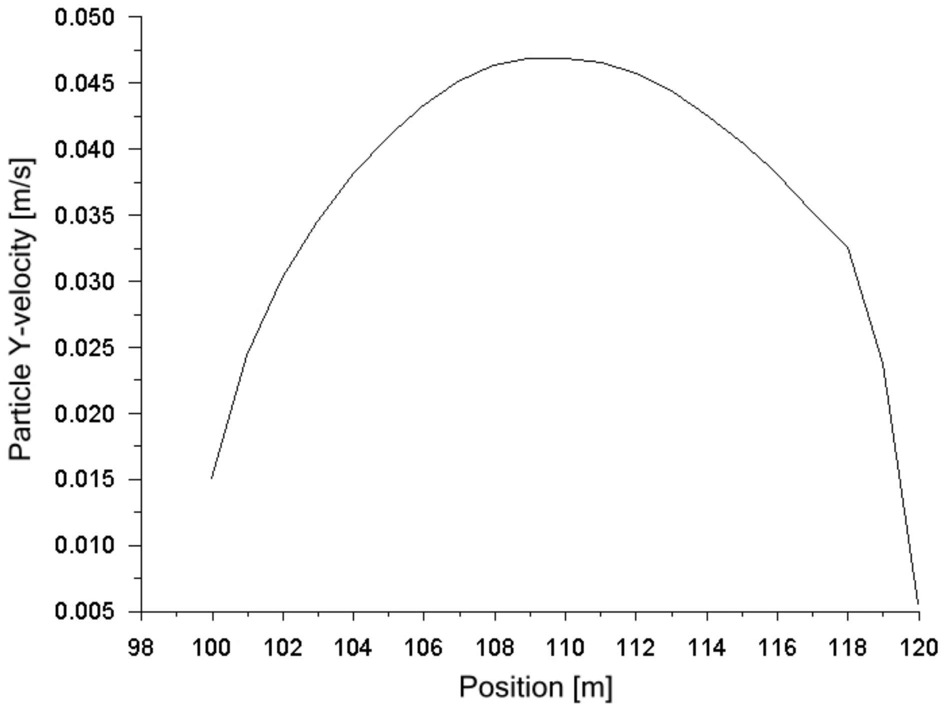


(a) Wind velocity magnitude [m/s]



(b) Particle tracking emitted from the background emissions, coloured by their concentration level [kg/m^3]

Figure 18 – Results of the simulations for the rural design after 6,000 time steps



(c) Particle Y-velocity [m/s] along the X-axis [m]

Figure 18 – Results of the simulations for the rural design after 6,000 time steps

G Food standards for leaf vegetables

Table 11 – Maximum levels for cadmium, lead and nitrate in leaf vegetables and spinach [mg/kg fresh weight], from different food standard instances: the Codex Alimentarius and the European Commission.

Contaminants	Foodstuffs	Codex Alimentarius	European Commission
Cadmium	Leaf vegetables	0.20	0.20
Lead	Leaf vegetables	0.30	0.30
Nitrate	Fresh spinach	-	3,500
	Preserved, deep-frozen or frozen spinach	-	2,000