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# Simulating and visualising data in environmental history: Airborne dust concentration from the Belval plant in Luxembourg (1911-1997)

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Dust Pollution, Environment, Data visualization, Simulation, Steel Industry, History of Luxembourg

This research combines current scientific knowledge and historical data to model the airborne dust concentration generated by the Belval steelworks in Esch-sur-Alzette between 1911 and 1997. The calculations are based on a model of atmospheric dispersion, using parameters such as production volumes, the presence of filter systems and meteorological data. Simulations, a form of data generation widely used in engineering, open new opportunities for the recreation of historical data. These historical data can be re-analysed and visualised on the basis of new and/or current perspectives. Visualisation of the simulated data offers insights into the extent and variability of dust concentrations over time, along with the underlying reasons (e.g. wars, technical innovations, …). An interdisciplinary approach allows for the integration of chemical and health perspectives, which are placed in a historical context.

Our main aim is to explore new ways of generating, validating, analysing and visualising historical data through interdisciplinary collaboration, rather than to validate a model for the study of historical dust pollution. This work discusses (a) the model, (b) the parameters used, (c) the results of the dust simulation, (d) the impact on health, (e) the historical sources, and (f) the limitations of the model and the challenges involved in visualising and simulating historical data. The research is an interdisciplinary collaboration between the REMIX project (which focuses on the history of the Minett region, in the framework of the event Esch-sur-Alzette – European Capital of Culture 2022) and the LuxTIME project (which attempts to build and visualise historical datasets, with the aim of studying the impact of local environmental changes).

## Introduction

Air pollution has a history. In today’s society, this historicity is most commonly perceived in the context of global warming, where the ‘weight’ of billions of tonnes of carbon dioxide released in the past has become a factor of major importance for our global ecosystem. The mechanism behind this has been elegantly described by Malm, who observed that our climate has essentially become a ‘product of past emissions’, while the ‘emissions produced […][today will generate] their greatest impact on generations not yet born’. For Malm, present-day emissions are effectively ‘invisible missiles aimed at the future’ (*Malm 2016*). The adjective ‘invisible’ is rather important here. After all, the peculiar interrelationship between past, present and future is not the only paradoxical characteristic of air pollution history (on this interrelationship, see also (*Uekötter 2020*). Another paradox is the fact that the ongoing global warming is caused by a gas that, when encountered under everyday circumstances, is both invisible and odourless. This lack of perceptibility does not imply, however, that pollution problems went unnoticed by previous generations. Prior to the scientific and societal problematisation of the greenhouse effect, other manifestations of air pollution – such as dust, dark smoke, soot particles and stench – were particularly palpable in cities and industrial regions, and as such a regular source of indignation (for two classic studies on this indignation, see (*Brüggemeier, Rommelspacher 1992*, *Mosley 2001*).

The southwest of the Grand Duchy of Luxembourg, an important iron and steelmaking region from the 1870s onward, was one of those places where people were constantly faced with air pollution that was as omnipresent as the industrial plants themselves.  
[For the economic and social history of Luxembourg’s metallurgical industry, see the seven-volume series *Terres Rouges: Histoire de la sidérurgie luxembourgeoise*, published from 2009 to 2022 by the National Archives of Luxembourg. It should be noted that this series does not discuss pollution problems.]  
In the Minett, as Luxembourg’s metallurgical region is called, the soot and smoke of the steelworks were part of a ‘sensescape’ that could be seen and smelled on a near-permanent basis (on the notion of sensescape, see (*Pritchard, Zimring 2020*)). To borrow the words of an elderly inhabitant of Dudelange, who recently reminisced about his life in Luxembourg’s industrial region: day in, day out, ‘the dust and dirt fell from the skies’ (*Back-Hoffmann 2021*). In order to objectify the severity of this problem, several scientific studies were carried out in the Minett towns of Differdange and Esch-sur-Alzette between the late 1930s and the early 1970s, with the specific aim of measuring the typical quantity of airborne dust particles on or near industrial sites. Yet these measurements – which we discuss in ([section 8.2](#anchor-section-8-2)) – only lasted for a limited period (for instance three months), and thus only provide a snapshot in time.

In this contribution, we attempt to create a *long-term* picture of past dust pollution levels by using the Belval iron and steel complex in Esch-sur-Alzette – the informal capital of the Minett (hereafter: Esch) – as a test case ([Figure 1](#anchor-figure-1)). For this purpose, historians, metallurgy experts, chemists and data visualisation specialists collaborated to analyse a major metallurgical pollutant: dust. We present a simulation and visualisation of the diachronic evolution of local airborne dust concentrations in the vicinity of the Belval plant, using various parameters as input for our model. These include the production numbers of the plant throughout the 20th century, the production process (e.g. LD-AC or Thomas for steelmaking), the typical usage of filtering systems, and the prevailing wind directions over time. Based on this data set, we offer a plausible approximation of how the dust emissions of the Belval iron and steel complex affected local air quality between 1911 (the first year of operation) and 1997 (when the last blast furnace was shut down).

An important precedent for modelling in environmental history can be found in the work of Tarr, who investigated emissions of man-made components such as pesticides, herbicides and heavy metals in the estuary of the Hudson and Raritan rivers between 1700 and 1980. To achieve this aim, Tarr collaborated with physicists and environmental engineers ((*Tarr 1996*); see also (*Tarr 2021*)). Likewise, in their 2021 study on climate change and its effects on people, Pfister and Wanner attempted to reconcile the scientific cultures of the natural sciences and the humanities: ‘Scientists explain how natural systems work, while (environmental) historians tell stories of people who grapple with the effects of weather and climate’ (*Pfister, Wanner 2021*). As such, Pfister’s and Wanner’s research is in line with an approach outlined by Guldi and Armitage, who have discussed the role of history in the process of understanding ‘the multiple pasts which gave rise to our conflicted present’. Regarding climate change, Guldi and Armitage have argued that ‘history, with its rich, material understanding of human experience and institutions and its apprehension of multiple causality, is re-entering the arena of long-term discussions of time where evolutionary biologists, archaeologists, climate scientists, and economists have long been the only protagonists’ (*Guldi, Armitage 2014*).

Similar to the way in which environmental history and the history of technology have become more entangled in the last decade (resulting in the development of a crossover field known as ‘envirotech’, e.g. (*Pritchard, Zimring 2020*)), interdisciplinary endeavours between the human and natural sciences are indeed essential if one wants to adequately evaluate environmental changes that have occurred in the past. This has been made explicit by Massard-Guilbaud:

*How can we write a history of climate without contacting climatologists? A history of pollution without touching on chemistry? A history of sanitation systems or energy resources without taking an interest in technology? Let us note, moreover, that it is not only historians who are discovering this need for interdisciplinarity; specialists in other disciplines […] are also approaching historians […] on environmental issues because […] they feel the need to do so.* (*Massard-Guilbaud 2007*) [All translations throughout have been done by the authors.]

The research questions that motivate our own interdisciplinary research are as follows. Throughout the 20th century, how were people living near the Belval iron and steel complex affected by dust pollution? Can this pollution from the past be quantified and displayed on a map? And how did it evolve over time? Using modelling and simulation with historical data as input, we generate new data that can answer such questions, thereby uniting the points of view of the exact sciences (e.g. the health impact of various concentration levels) and history (e.g. the industrial development of the region and the societal narratives about pollution). We hypothesise that the pollution generated by the Belval plant affected many (if not all) of the inhabited quarters of both Esch and the surrounding municipalities, including some on French territory, which would make Belval a case of cross-border air pollution.

It must be emphasised that our contribution offers only an *estimation* of pollution values, due to the limitations inherent in any simulation. In the current study, such limitations include the lack of adequate corporate sources on the presence and efficiency of filtering systems, forcing a reliance on assumptions (based on data in non-Luxembourgish secondary literature on ideal typical metallurgical filtering systems). Another limitation of our model is the omission of other pollution sources, such as iron and steel complexes other than Belval, non-metallurgical industrial complexes, traffic and domestic heating. As such, we agree with a warning recently posited by Parr concerning interdisciplinary work. While she endorsed collaborations between ‘researchers in environmental history and the history of technology’ and scientists from fields like ‘metallurgy [and] bio-chemistry […]’, Parr pointed at possible incompatibilities between historical science and the natural sciences, due to the latter’s tendency to ‘simplify’ for the purpose of experimentation, as well as to ‘derogate knowledge and reasoning that is not readily represented in symbols and signs’ (*Parr 2010*). In our interdisciplinary contribution, we take a rather modest view on this matter, by explicitly pointing at the potential of our research as well as the lacunae and possibilities for future improvement.

The broader historiographical relevance of our undertaking is manifold. Investigating historical pollution levels can provide insights into the long-term environmental impact of industrial activities, as it helps to assess the lasting effects of pollution on ecosystems and human populations over time. Studying past pollution can also shed light on the disparities in the distribution of environmental hazards and their impact on communities: a phenomenon nowadays known as environmental (in)justice (on its relevance in historiography, see (*Uekötter 2017*). Finally, by sharing our findings with a non-specialised audience (as we have done in the context of a 2022 online exhibition), our research also contributes to educating the local community about the historical context of pollution. In an ideal scenario, such education has the potential to cultivate a heightened sense of responsibility for environmental stewardship.

The structure of our article is as follows. In ([section 2](#anchor-section-2)) we discuss the terms ‘modelling’ and ‘simulation’, their history and application across disciplines, and their largely untapped potential in the humanities. ([Section 3](#anchor-section-3)) explains the general impact of dust pollution on health, in order to provide a basis for the subsequent analysis of our results. ([Section 4](#anchor-section-4)) establishes the historical context of the metallurgical industry in Luxembourg, the Minett region and Esch, while also briefly exploring some societal narratives about pollution. In ([section 5](#anchor-section-5)) we introduce steelmaking production techniques as well as their evolution and impact on dust pollution. ([Section 6](#anchor-section-6)) explains the actual simulation process by focusing on the data generated by the dispersion model. Here, we discuss the data basis and the model specifications, in relation to our hypothesis about the impact of pollution on the inhabitants of Esch and the surrounding area. In ([section 7](#anchor-section-7)) we outline the data visualisation process, while ([section 8](#anchor-section-8)) contains an analysis of the results, including the validation of the model used (a basic Gaussian dispersion model that has already been proven through its use in similar scenarios). Additionally, a comparison of the model results against available measurements is presented in ([subsection 8.2](#anchor-section-8-2)), while the limitations and potential ways to improve the model in future research are covered in ([section 8.3](#anchor-section-8-3)) and ([8.4](#anchor-section-8-4)). For future research on historical dust pollution, the model could be used with alternative data sources for new simulations, or new models could be tested adding new variables. Our conclusions are offered in the final ([section 9](#anchor-section-9)).

## Modelling and simulation

Since modelling and simulation are key elements in our research, a brief introduction of terms and usage across disciplines is appropriate. Banks defined simulation as ‘the imitation of the operation of a real-worId process or system over time’ that can model both existing and conceptual systems (*Banks 1999*). As such, simulation is used for a variety of purposes including prediction, performance, training, entertainment, proof and discovery. While *induction* can be used to find patterns in data and *deduction* to find consequences of assumptions, *simulation* generates data that can be analysed inductively (*Carson II 2005*).

Initiated during the Second World War ‘to address problems too complex for theory and too remote from laboratory materials for experiment’ (*Galison 1996*), simulation spread through the social sciences by the end of the 1960s, where it was (and still is) often used for modelling artificial populations and investigating human behaviour (*Lebherz, Zeyen, Hess, Bergmann, Timm, Burch, Hildenbrandt, Moulin 2018*). More specifically in the field of pollution studies, spatial analysis has been proven useful: Cichowicz and Dobrzanski, for instance, studied the concentration of air pollution using computer modelling of pollutant dispersion based on real measurements in the city of Łódź, Poland (*Cichowicz, Dobrzański 2022*). Wang and Chen predicted the spatial concentration distributions of airborne pollutants, using a GIS-based multi-source and multi-box modelling approach (*Wang, Chen 2013*). Banerjee et al. performed an assessment of ambient NO2 concentration in Pantnagar, India through a simulation of two mathematical dispersive models (*Banerjee, Barman, Srivastava 2011*).

However, notwithstanding a few exceptions, simulation has remained ‘almost unknown to the humanities’ (*McCarty 2016*). Apart from the environmental historical research mentioned in the ([introduction](#anchor-introduction)), Lebherz et al. have presented a case of text mining by scientific workflows and computer simulation, with the aim of investigating potential influences on the author’s literary productivity. In this context, they have identified four prerequisites: a solid data basis, the specification and construction of a model, the definition of hypotheses to answer research questions, and the reuse of proven models in similar scenarios (*Lebherz, Zeyen, Hess, Bergmann, Timm, Burch, Hildenbrandt, Moulin 2018*). Simulation is also frequently used in certain fields of archaeological research, such as evolutionary archaeology and the study of human evolution (*Lake 2014*). Champion has discussed the distinction between model (‘a physical or digital representation of a product or process’) and simulation (‘the re-configurative use of a model to reveal new and potential aspects’) (*Champion 2016*). In the context of the humanities, McCarty has referred to modelling as ‘the analogical bridge between computing and the interpretative disciplines’ that ‘keeps the digital construct separate, informing humanistic research both by what it discovers and especially by what it cannot’. The defining moment of simulation occurs ‘when it becomes the only way to know something or to form a coherent picture from fragmentary knowledge’ (*McCarty 2016*).

In our research, the model and simulation are inspired by the exact sciences described above. Our innovativeness stems from the use of historical data to populate the parameters, as well as from the integration of our results in a public history framework.

## Dust pollution from a chemical and health perspective

Examining the airborne dust concentration from the Belval plant entails delving into both the chemical and health dimensions of dust pollution. Understanding the various particle types, their sizes and associated implications is essential for establishing the pertinence of this information to the primary research objectives.

Pollution caused by dust (atmospheric particulate matter) is a global problem, both historically and in the present (*Butte, Heinzow 2002*, *Han, Liu, Feng, Mao, Sun, Wang, Wang 2021*). Dust from various anthropogenic sources such as industry, households and traffic is a major source of chemical contamination and has a negative health impact. Dust particles can also originate from natural sources, like pollen, microorganisms and the natural erosion of soils. The size, origin and chemical composition of particles play a major role when looking at health and environmental effects. The particles under consideration in this study and their implications for health and environment are discussed below.

Airborne dust comes in all shapes and sizes, which are either visible or invisible to the naked eye (aerodynamic diameter 1 to 400 µm) (*Kumar, Kumar 2018*). Large particles settle quickly (> 100 µm) or are trapped in the nose, mouth and larynx region when inhaled (*inhalable* fraction ≤ 100 µm), as shown in ([Figure 2](#anchor-figure-2)) (*Wippich, Rissler, Koppisch, Breuer 2020*). Smaller particles stay for longer in the air, while very small particles can penetrate the respiratory system. The *respirable* dust fraction that can enter the alveolar region is defined to be below an aerodynamic diameter of 10 µm, independent of the particle’s length (*WHO 2022*). Small particles that remain in the gas-exchange region of the lungs can cause allergic reactions, cancer and other serious diseases or disorders (*Wippich, Rissler, Koppisch, Breuer 2020*, *WHO 2022*, *Bala, Tabaku 2010*).

Dust sources can be either point or area sources, from where particles with long lifetimes can spread over many kilometres (*Leelőssy, Molnár, Izsák, Havasi, Lagzi, Mészáros 2014*). Their chemical composition is essentially linked to their origin: during the extraction and processing of minerals, for instance, dust containing silica is often released in the air, which can result in permanent health damage (e.g. diseases such as silicosis) (*Mlika, Adigun, Bhutta 2022*). Likewise, metallic dusts (e.g. lead and cadmium) from smelters cause harm to fauna and flora, as do chemical dusts created in agriculture (e.g. pesticides), vegetable dusts (e.g. wood, cotton), moulds and spores (*WHO 2022*). Other air pollutants are created by the reaction of sunlight with atmospheric compounds, leading to photochemical smog (sunlight reacting with volatile organic compounds and nitrogen oxides).

The iron and steel industry is a major contributor to air pollution. In the past, burning coal for steel production produced vast amounts of black coal dust, resulting in fine particles covering cities and regions. Such particles often contain silica and various metals; those with a diameter below 2.5 µm can easily enter the alveoli (the gas-exchange regions of the lungs) ([Figure 2](#anchor-figure-2)) and cause serious harm (*Su, Ding, Zhuang 2020*). Early types of filtering devices based on cyclone techniques only removed larger particles, thus leaving smaller fractions uncaptured (*Imperial Systems, Inc. 2019*).

With the rise of environmental regulation and technical advances from the mid-20th century onward, it became possible to significantly decrease dust emissions as long as steel companies were prepared to make the necessary investments. The decrease was mainly enabled by improved filtering techniques, including shaker bag collectors, reverse air or pulse jet baghouses, and cartridge collectors (*Imperial Systems, Inc. 2019*). However, even today many iron and steel plants continue to rely on coal fuel (the ‘dirtiest’ but also cheapest option available), with little concern for the environmental effects and the availability of cleaner techniques (*Wildsight 2020*). Besides greenhouse gases like nitrous oxide (NO), steelmaking generates airborne contaminants (*Koponen, Gustafsson, Kalliomäki, Kalliomäki, Moilanen, Pyy 1980*). Metals like cobalt, lead and chromium are released into the atmosphere (*Nurul, Shamsul, Noor Hassim 2016*) when not filtered appropriately, and so are concentrations of polycyclic aromatic hydrocarbons (PAHs), iron oxides and sulphur dioxide (SO) (*Bala, Tabaku 2010*). Historically as well as in the present, respirable particle emissions from the iron and steel industry pose risks to human health (*Valenti, Pozzi, Busia, Mazza, Bossi, De Marco, Ruprecht, Borgini, Boffi 2016*).

## Esch-sur-Alzette and the Belval metallurgical complex: a brief historical overview

Measured per capita, Luxembourg was the world’s foremost iron and steel producer throughout the 20th century (for global production trends, see (*Hemmer 1953*)). While all the Minett’s towns were severely affected by air pollution, Esch had the specific characteristic of being surrounded by iron and steel complexes. The local historians Assa and Pagliarini have rightfully noted that ‘Esch and its factories formed one unity; their evolution occurred along parallel lines’ (*Assa, Pagliarini 1998*). From the moment the first blast furnace in Esch started operating, the urban infrastructure of this ‘mushroom town’ (*Knebeler, Scuto 2010*) indeed developed almost exclusively to serve the metallurgical industry. An engraving from the 1920s shows that iron and steel complexes could be found to the southwest of Esch (the *Terres Rouges* plant, established in 1872), to the east (the Esch-Schifflange plant, 1871) and to the west (the Belval plant, 1911). Other polluting factories, such as a cement factory, a brewery and a coal-fired power plant (which supplied electricity to the steelworks) were also present in the town throughout much of industrial era (for a general overview, see (*Scuto 1993*) ). A scale model of the Minett, made for the 1937 World’s Fair in Paris, clearly illustrates how Esch was ‘embraced’ by factories and, consequently, by industrial smoke and dust (on Luxembourg’s participation at the 1937 World’s Fair, see (*Millim 2014*)).

Contrary to present-day popular belief (e.g. (*Moia 1998*, *Logelin-Simon 2006*, *Back-Hoffmann 2021*)), the air pollution caused by the metallurgical complexes of the Minett was not uncontested by the local population. From the early 20th century onwards, inhabitants voiced their criticism about dusty factory smoke through articles in newspapers and magazines, readers’ letters and interventions in parliament and municipal council meetings. This paragraph will shortly explore a few criticisms concerning the Belval complex from the period when the plant was established. A more in-depth analysis of complaints from inhabitants about air pollution in the entire Minett region is offered in a separate article, which focuses on the period of the *Trente Glorieuses* (c. 1945-1965) and conceptualises the role of newspapers, politicians and scientists as ‘mediators’ in the public debate on air pollution (*Van de Maele forthcoming*).

From around 1900, about three decades after the dawn of industrialisation in Luxembourg, the country’s press began to report on the so-called ‘plagues’ of dust and smoke (in German: *Staubplage*, *Rauchplage*). These ‘plagues’ were reported to soil clothes and buildings, irritate lungs and eyes, and affect animal and plant life. As early as 1899, for example, the newspaper *Luxemburger Wort* published a remarkably lucid analysis of air pollution in industrial regions (for the history of this newspaper, see (9139636/SCK8QXWH)). Despite its conservative, pro-business profile, the newspaper offered a remarkably modern-sounding, holistic approach towards both human and non-human nature, thus offering a rather bleak picture of the industrial era:

*No more than fifteen years ago, everyone took for granted that a chimney should smoke, and every stranger who came to a factory town looked in admiration at the myriad of smoking chimneys […]. Even those who were directly harmed by the smoke considered this to be so inevitable that they hardly ever complained about it, and when they did, they were told – with a shrug – that nothing could be changed. And so for decades, the vegetation in industrial areas withered, entire forests had to be cut down prematurely […], and soot particles and poisonous gases inhaled by human lungs slowly but surely planted the germ of many a deadly disease.* (*Luxemburger Wort für Wahrheit und Recht 1899*)

Already around this time, awareness about the detrimental side effects of metallurgical dust also existed on a governmental level. This becomes evident in a 1910 investigation undertaken at the instigation of the Luxembourg Prime Minister in response to the construction request for the Belval plant submitted by the German corporation Gelsenkirchener Bergwerks AG. At that time, the corporation had recently acquired a plot of forested land just to the west of Esch. Conceived as a vertically integrated plant, the Belval complex was to include two blast furnaces (later supplemented with a third), steel converters, a sintering plant and rolling mills. In a letter to three engineers (who were most likely state-employed), the Prime Minister expressed reservations about the addition of yet another metallurgical factory in the Minett: ‘[…] [It] is necessary to investigate all [technical] methods to curtail noise […] and dust […].’ (9139636/88ILKR6H)

Consistent with the legal framework of the time (*Parmentier 2008*), the Prime Minister’s reservations were mainly driven by a desire to minimise damage to the private property of adjacent landowners; a true ‘environmental’ awareness (as can be seen embryonically in the very *avant-garde* 1899 newspaper article mentioned above) was not yet part of the politicians’ intellectual *habitus*. In response, the experts offered a highly ambiguous evaluation of the prospective plant. Although they acknowledged the existence of a pollution burden, this burden was considered to be a ‘normal’ phenomenon in industrial regions:

*The inconveniences these kinds of establishment can have for certain [neighbouring] owners in terms of their enjoyment of the tranquillity and pure air of the countryside are not to be denied. These inconveniences stem from the vapours and dust that detract from the purity of the air, as well as the noise caused by the machines and the movement of workers […]. Such inconveniences are common in industrial centres; everyone experiences them in Esch, Differdange, Rodange, Dudelange, etc. Yet they cannot be invoked as a reason to refuse authorisation.* (9139636/83GK3TZT)

This discourse was typical of the professional ethos of late-19th and early-20th-century engineers, who typically saw themselves as expert organisers, both within and beyond their technical sphere of competence (on the role of engineers in Luxembourg society, see (*Glesener, Wilhelm* )). As such, the engineers also gave advice about the moral economy in which the steelmaking was to take place: in their view, the imperative of economic development outweighed the time-honoured right of neighbouring inhabitants to ‘pure’ air. The engineers’ opinion proved to be decisive: shortly after the governmental enquiry, a green light was given to the Gelsenkirchener Bergwerks AG, and in 1911 the two blast furnaces of the iron and steel complex (which would later become known as Belval) were fired up. Soon enough, newspapers would again voice concerns about the increasing dust problem in Esch. In April 1914, just three months before the start of the First World War, another conservative newspaper, the *Obermosel-Zeitung*, for instance voiced concerns about the worsening ‘smoke plague’:

*If any town far and wide suffers greatly from the smoke plague, it is Esch. No fewer than 30 to 40 blast furnace chimneys in the town’s immediate vicinity spew their contents on the Minett’s capital day and night. If a resourceful person were to come up with an effective invention against the smoke plague, he should certainly file a patent in Esch. It is only a small consolation for the people of Esch to hear that the smoke plague is also known to be a great evil in other places, and that in many cases desperate efforts are being made to combat it […].* (*Obermosel-Zeitung 1914*)

Still in 1914, the Esch-based architect Paul Flesch declared in a municipal council meeting that Esch should keep a corridor without industry in the north, to allow the town’s 30 000 inhabitants ‘to breathe some clean air for at least a few days a year’. With his call for the incorporation of public hygiene principles in urban planning policies, Flesch sought to pair economic development with a more decent quality of life for the town’s inhabitants (*Scuto 2005*). As it turned out, the north of Esch would effectively remain industry-free – even though the ‘right to produce’ (and, consequently, the right to pollute) of the existing iron and steel complexes would never be called into question by local and national authorities. Using a term from German historiography (e.g. (*Geissler 2016*)), it can be said that these authorities consistently affirmed the *Ortsüblichkeit* (‘geographical appropriateness’) of industry. This principle was further underpinned by the powerful political and economic position of the ARBED company (*Aciéries réunies de Burbach-Eich-Dudelange*), which took over ownership of the Belval complex in 1919 (*Knebeler, Scuto 2010*). In this constellation, the plant would thrive: between 1911 and 1997, a total of almost 80 million tonnes of iron was produced at the Belval site – or about one third of Luxembourg’s total production during that period. Belval’s corresponding steel production amounted to approximately 75 million tonnes – a number that is continuing to grow to this day, as the steelworks are still in operation even after the closure of the last blast furnace in 1997 (for production numbers, see (*Knebeler, Scuto 2010*)). As we will investigate in the following sections, these very high production levels also had a severe impact on the local environment.

## Steelmaking techniques in Luxembourg

As steelmaking techniques developed, the degree of dust pollution resulting from the steel industry in the Minett varied over time. Initially, at the onset of industrialisation in the 1870s, Luxembourg’s plants used the Bessemer process, the first industrial method to produce steel from molten pig iron, which was invented in the 1850s and complemented in 1864 by the Siemens-Martin process (*Knebeler 2011*, *Metz 1972*). Impurities were removed by oxidation, i.e. by blowing air through the molten iron. However, as the iron ore found in the Minett is high in phosphorous, only low-quality steel could be manufactured (*Knebeler 2011*). This changed with the modification of the Bessemer process by Sidney Gilchrist Thomas, who used dolomite, which is basic, as the converter lining (instead of packed sand, which is acidic), thereby removing the phosphorous from the steel into the slag (*Knebeler 2011*, *Metz 1972*). In Luxembourg, the first Thomas steel was produced in 1886; the process was complemented by electric arc furnace (EAF) steelmaking after 1900. From the 1950s onwards, pure oxygen processes like the LD-AC process (*Linz-Donawitz – ARBED – Centre national de recherches métallurgiques de Liège*) were predominantly used to produce higher quality steel with fewer impurities compared to Thomas steel (*Knebeler 2011*, *Metz 1972*). [Other techniques replacing Thomas steel were the Lance Bubbling Equilibrium (LBE), ARBED Ladle Treatment (ALT) or LD Kaldo, and Rotovert. (*Knebeler 2011*, *Metz 1972*)]

The LD-AC method was reported to generate less dust (9139636/EG7EKVXT). In a 1972 article, Metz signalled that the steelworks in the Minett used two principal techniques to perform dedusting: electro-static purification with negatively charged dust particles collected on a positive collection plate, and wet processes which retained dust with water (*Metz 1972*). The efficiency of these processes seems to have been limited, however. According to Hoffmann (1974), who based her findings on an undisclosed source, dust pollution levels in Esch regularly exceeded 1.8 g/m/day, which was well beyond the West German environmental limits of the time (0.42 g/m/day for urban zones and 0.85 g/m/day for industrial zones) (*Hoffmann 1974*). But even though she was a critic of the steel industry, Hoffmann claimed that 90% of the air pollution in Luxembourg resulted from households (oil heating) and traffic, and not from the iron and steel works – a position in line with that of the steel industry (*Metz 1972*). A number of measurements undertaken between the mid-1950s and the early 1970s, which we discuss below (([section 8.2](#anchor-section-8-2)),), indicate that this estimation was most likely too flattering for the metallurgical industry, and that the airborne iron oxide load caused by steel processes was probably much higher.

By the time Metz and Hoffmann published their articles, governmental awareness about the environmental impact of the iron and steel industry was on the rise. This rise was spurred by multiple factors, including decades of public complaints, the international emergence of the ‘modern’ environmental movement in the second half of the 1960s, and the ongoing scientific research on metallurgical pollution conducted in the transnational framework of the European Coal and Steel Community (*Van de Maele forthcoming*). As a result, in the mid-1970s, the demand for the ‘polluter pays’ principle became stronger, eventually requiring Luxembourg’s industry to minimise its environmental impact ((*Hoffmann 1974*); on the worldwide rise of environmental policy-making during the 1970s, see for instance (*Jarrige, Le Roux 2017*, *Buelens 2022*, *Uekötter 2020*)). The iron oxide content in the Minett’s atmosphere was addressed in a 1976 parliamentary debate, when an MP stated that the ‘red clouds’ of iron oxide were predominantly a result of Thomas steel production, while the LD-AC process (which was usually operated with pre-installed filters) was reported to generate less dust (9139636/EG7EKVXT). In Luxembourg, the last Thomas steel was produced in 1977 (*Metz 1972*, *Hoffmann 1974*).

## The simulation process

The calculation of our dust simulation model – estimating dust concentrations from 1911 to 1997 – was performed at our request by Inspyro, a technical consultancy company assisting metallurgical enterprises. The various sources (and their limitations) used as input data for the Gaussian model are explained below.

There are several ways to create the atmospheric dispersion models needed to understand and predict air pollution. Gaussian, Lagrangian, Eulerian and computational fluid dynamics models all offer possibilities, differing in their mathematical complexity and field of application. [Gaussian models assume a normal statistical distribution (parabolic behaviour near the origin of the coordinates, “bell curve”) and are typically used for buoyant air pollution plumes. This approach historically dominated dispersion models with a number of simplifications to be taken in the advection-diffusion equations. Lagrangian models use trajectories – calculated using ordinary differential equations – of air pollutants determined by e.g. wind field, buoyancy and turbulence (*Leelőssy, Molnár, Izsák, Havasi, Lagzi, Mészáros 2014*). Pollutant particles are followed in time and space along their trajectories. Eulerian models use a fixed coordinate frame providing a spatiotemporal evolution of pollutant concentration at each time step and point in the grid. For environmental and health protection measures, computational fluid dynamics models are often used in complex geometry where a fine grid resolution is required to calculate turbulence effects (Lagrangian and Eulerian: coarse grid). This model does account for flow velocities and turbulence in a complex 3D terrain, unlike the Gaussian approach (*Leelőssy, Molnár, Izsák, Havasi, Lagzi, Mészáros 2014*). For more information and a detailed comparison see Leelőssy (*Leelőssy, Molnár, Izsák, Havasi, Lagzi, Mészáros 2014*).] All models require the input of parameters like meteorological data, emission parameters and terrain information. To develop such a model, an interdisciplinary approach including disciplines like meteorology, chemistry and physics is often the best option. The output data is usually plotted on maps indicating areas of higher/lower air pollution concentrations and therefore higher/lower health risk.

In our case, a basic Gaussian dispersion model, as shown by Leelőssy et al. – known for its fast response time in the application of long-term average loads for distances between 1 and 100 km – was used (*Leelőssy, Molnár, Izsák, Havasi, Lagzi, Mészáros 2014*). The equation used (1), based on the Gaussian plume model for atmospheric dispersion modelling, is shown below.

A detailed formula derivation can be found in Stockie’s ‘Mathematics of atmospheric dispersion modelling’. Stockie defines dispersion as the ‘combination of turbulent diffusion and advection by the wind’ (*Stockie 2011*). Atmospheric contaminant concentrations can therefore be explained using the advection-diffusion equation. Using the simplified model of a Gaussian plume, it is assumed that air contaminants come unidirectionally (given the wind direction) from one point source – here one chimney of the Belval steel plant –, as outlined in ([Figure 5](#anchor-figure-5)).

In formula (1) is defined as the time-averaged concentration at a given position, Q represents the constant emission rate [kg/s] and (x,y,z) stand for the wind directions (downwind, crosswind, vertical direction) with the standard deviations and . is the time-averaged wind speed at contaminant release height h (see ([Figure 5](#anchor-figure-5))). Moreover, a homogeneous steady-state flow at the point source (0;0;h) is assumed (*Leelőssy, Molnár, Izsák, Havasi, Lagzi, Mészáros 2014*).

For the Belval case, only one chimney of the steel plant was assumed to be the point source. To calculate the amount of dust produced per month, the various steelmaking processes were categorised; sintering and crushing of iron ore were the main processes contributing to dust production during ironmaking. The average amounts of dust produced by the three steelmaking processes were subsequently used to calculate the amount of dust generated during the production of raw iron. For electric steel production (using an electric arc furnace, EAF), the average amount of dust was multiplied by the amount of steel produced (see ([Figure 6](#anchor-figure-6))). The same approach was applied to Thomas steel and LD-AC steel. Annual steel production data at the Belval plant was retrieved from a table reproduced in a study by Knebeler and Scuto (*Knebeler, Scuto 2010*). This table includes the production data of steel in tonnes per steelmaking technique (Thomas, LD-AC, EAF, total steel) per year, shown in ([Figure 6](#anchor-figure-6)). As the simulation output shows, the dust concentrations are calculated as averages per month. (The annual production values turn out to be a limitation, since monthly data would generate a more exact output of the model.) The hypothetical average dust values generated per process (blast furnace, sintering furnace, EAF and LD-AC) were taken from Schueneman, as summarised in ([Table 1](#anchor-table-1)) (*Schueneman 1963*). Schueneman offered typical values for steel plants in the US in 1963; as such, our hypothetical average dust values offer only an estimation of dust-producing steel processes in Luxembourg from 1911 to 1997.

The hypothetical installation date of filters (with varying efficiencies) was likewise taken from Schueneman (*Schueneman 1963*) ([Table 1](#anchor-table-1)). Based on this hypothesis, steel production techniques in Belval after 1963 were assumed to have state-of-the-art filters installed. Again, the installation dates are typical estimates for US steel plants until 1963, which will not correspond 1:1 with our case study on Luxembourg. We used these assumptions because of the lack of literature on the historical presence and efficiency of filter systems in the European iron and steel industry. [Table 1](#anchor-table-1) summarises the filters installed per technique (based on Schueneman); the amount of dust caught by a filter was subtracted from the total amount produced. Afterwards the calculated amount of dust in t/year was converted into g/sec.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Technique | Average dust production [g/t] | Installation year | Filter | Efficiency[%] |
| **Blast furnace** |  |  | Preliminary |  |
| **Blast furnace** |  |  | High Efficiency |  |
| **Blast furnace** |  |  | State of the art |  |
| **Sintering furnace** |  |  | Centrifugal separators |  |
| **EAF** |  |  | No filters | - |
| **LD-AC** |  |  | State of the art |  |

To determine the wind directions and velocities per year and month, weather data from the yearly meteorological reports for Luxembourg City (about 20 km from Esch) were used and converted from the Beaufort scale to m/s (9139636/W8XESNTP). Since weather data for the years 1911-1949 were not available in digitised form, an average wind profile consisting of speed and direction – taken from the 10th and 20th day of each month – was created and used for all years, based on the data for the 1949-1997 period (see ([Figure 7](#anchor-figure-7))).

Using this input data, the dust concentration (g/m) of all 15m x 15m x 1m cells – in a 2.5 km radius around the Belval plant – was calculated, using a MATLAB (9139636/IPI8LNCN) script based on equation (1). The code was generated by metallurgical experts and is therefore not included here. [The metallurgical experts who performed the calculation for Inspyro were Sander Arnout, Yannick Cryns and Cem Tekin.] Nevertheless, we show the input, output (csv files) and further processing (data visualization) of the MATLAB script. MATLAB is a computing environment and a programming language used by engineers and scientists, aiding with data analytics, linear algebra, signal processing, etc. MATLAB is a matrix-based language that includes many specialized libraries to solve engineering and scientific problems. Although it also includes plotting capabilities, we used Python for the data visualization, as it allows for more flexibility.

The visualisation of the model was generated using a Python in Jupyter notebook, from 1044 generated matrices of 302x302 values, saved in separate csv files. Each file corresponds to a month and a year between January 1911 and December 1997. The data is not geocoded; instead, the reference point (or source point) is one hypothetical chimney of the steelworks, located at the centre of the matrix, from which concentration values are calculated. The visualisation process of the data is explained in ([section 7](#anchor-section-7)).

It can be said in advance that the calculated concentration values in our study are most likely to be underestimations, since only one emission source in southern Luxembourg was considered (thus eliminating many others). Yet, serving as an experiment, our analysis can be taken as a basis for further research (e.g. calculating the dust concentrations from all industrial plants in the entire Minett region). Other limitations and improvements of our model are discussed in ([section 8.3](#anchor-section-8-3)) and ([8.4](#anchor-section-8-4)).

START HERMENEUTICS

## Data visualisation

As introduced above, the data visualisation was generated using a Jupyter notebook with Python for a multi-layered approach, which allows us to share not only the narrative layer but also the data and the code. The data was not geocoded, since explicitly assigning coordinates to each concentration point in each dataset would have increased the volume of data considerably. Instead, the data was kept in the form of multiple matrices and positioned on the map using Google Earth to calculate the distance covered by the density matrix (see ([Figure 8](#anchor-figure-8))).

END HERMENEUTICS

START HERMENEUTICS

Initially, the option of using a historical map (see ([Figure 9](#anchor-figure-9))) was considered. This was discarded in favour of the more accurate calculation of distances offered by Google Earth, as well as by its possibility to generate a view with the steelworks at the centre.

END HERMENEUTICS

START HERMENEUTICS

The dust concentrations around the Belval plant (in g/) were visualised using a contour map with ten predefined levels. We used the extent parameter to plot the concentrations on the map, and a customised sequential colour palette to indicate the presence and concentration of dust.

END HERMENEUTICS

START HERMENEUTICS

Contour maps were generated for every month and year between January 1911 and December 1997 in English, French and German. For this purpose, the names of the main localities were translated; using Figma, they were added to the base maps extracted from Google Earth (see ([Figures 10 a and b](#anchor-figure-10))).

END HERMENEUTICS

START HERMENEUTICS

The visualisations were subsequently animated to show the evolution over time.

END HERMENEUTICS

START HERMENEUTICS

To visualise the impact of pollution in the inhabited quarters of Esch, we repeated the process with a zoomed-in map, thus highlighting the immediate vicinity of the Belval plant.

END HERMENEUTICS

START HERMENEUTICS

The videos were integrated into a [dedicated page](https://minett-stories.lu/en/story/air-pollution-visualized) of the [*Minett Stories*](https://minett-stories.lu/) virtual exhibition, which was launched in May 2022. Produced by the Centre for Contemporary and Digital History (University of Luxembourg) in connection with *Esch-sur-Alzette – European Capital of Culture 2022*, the exhibition offers twenty-two stories, outlining various transformations of landscapes, places and people, from the region’s industrialisation in the late 19th century to the crisis of the 1970s and the subsequent deindustrialisation. Instead of focusing on the often-told stories about the growth and success of the steel industry, *Minett Stories* explores everyday life in the Minett, with attention to questions such as environmental pollution. Our visualisation helps us to answer the initially formulated questions about the geographical distribution of dust pollution. By using various historical maps of Esch (see ([Figures 11 a,b,c](#anchor-figure-11))) and comparing them to the data visualisation for the same year, we can analyse which neighbourhoods were most affected over time. July has been chosen, as this is the month when the pollution typically reached the farthest in the town of Esch.

END HERMENEUTICS

It is clear, for example, that high dust levels were often prevalent in the centre of Esch; unsurprisingly, the western part of town was the most severely affected. Using a 1958 map of Esch as a reference, the affected areas primarily included the neighbourhoods of Uecht, Clair-Chêne, Al-Esch and Wobrecken. Moreover, from the outset, Belval’s dust pollution was a cross-border phenomenon, with the French villages of Rédange, Russange and Audun-le-Tiche (the latter itself the site of an ironworks from the 1880s to the 1960s) sharing the pollution burden with small Luxembourgish locations such as Soleuvre, Ehlerange and Belvaux.

## Final analysis

To conclude, we perform a critical evaluation and interpretation of the dust simulation. We explore the plausibility of the calculated values, comparing them to historical and current air pollution legislation, as well as to historical measurements. Limitations and possible ways to optimise the model are also discussed.

### Validation of the model

([Figure 13](#anchor-figure-13)) shows the summarised (total) amount of dust calculated by year versus steel production in tonnes, with dust in blue and production data in red. Important events like the (hypothetical) installation of filters are indicated. The graph further indicates a number of historical dates (such as the installation of filters, changing techniques, World War I and II, and the steel crisis from the second half of the 1970s onward), which all correspond to visible changes in the production and/or dust curves. This effect is for instance highly visible after 1965, with steel production increasing and the dust curve decreasing, owing to more intensive use of oxygen-based steelmaking and the hypothetical installation of ‘state-of-the-art’ filters (see ([section 6](#anchor-section-6)), and ([Table 1](#anchor-table-1)).

Besides checking the plausibility of the data, it is necessary to look at the actual meaning of the calculated dust values (with the highest calculated value being about 3 mg/ m in October 1929). To understand the effects of such values on human health, we will compare them to present-day regulatory limit values.

Directives and measures regarding air quality were first introduced by the European Economic Community in the 1970s. In subsequent decades, air pollution resulting from industry decreased significantly (*European Environment Agency EEA 2013*). In Luxembourg, the first legislation regarding air pollution was the ‘Loi du 21 juin 1976 relative à la lutte contre la pollution de l’atmosphère’. No limit values were laid down in this legislation. In the more recent context of EU law, Directive 2008/50/EC (*European Union 2008*) postulates limit values for different atmospheric pollutants to protect human health, including values for PM (25 µg/ m) and metals like Cd (5 ng/ m) (

### Comparison of the model results with air pollution measurements from the late 1930s to the early 1970s

To compare the simulated dust levels with real conditions, it is important to scrutinise historical documents on dust measurements in the Minett region. We were able to retrieve data about four measurements performed between the late 1930s and the early 1970s: 1939 (Schifflange, undertaken by the ARBED steel company) (9139636/WGAL532E), 1956-1957 (Differdange, undertaken by the government) (*Molitor, Barthel 1958*), 1966-1969 (Esch, undertaken by the municipality) (9139636/XP9DGUVF), and 1970-1971 (Belval, undertaken in an academic context) (9139636/7BPU6L8S). In all cases, dust was collected for a specified period through passive samplers (known as Bergerhoff devices). Both the motivation for the measurements and the methodological framework for the subsequent interpretation differed over time, as we will outline below.

In 1939, ARBED undertook dust measurements on the premises of its Schifflange iron and steel complex, located directly to the east of Esch (about 2.5 km from the Belval plant, which was owned by the same company) (9139636/WGAL532E). Investigated parameters included the amount of dust generated by the blast furnaces, particle sizes and the iron (Fe) content of the samples. This analysis was conducted for economic reasons only, with the aim of studying the potential for reusing blast furnace gas after the removal of dust particles. The analysis pointed out that very small dust particles (ranging from 0 to 10 µm) constituted about 25% of the total emitted dust mass; as noted in ([section 3](#anchor-section-3)),, such particles can penetrate the respiratory system and pose a threat to human health. In addition, around 48% of all dust released was reported to be made up of Fe: a very high iron content that was not unusual in the context of the Thomas steelmaking process. Even though the 1939 corporate investigation concluded that recycling and filtering techniques would be too expensive to implement, it is clear – in retrospect – that the installation of a dedicated filter could have resulted in significant health gains for both the local population and factory employees.

About two decades later, the scientists Molitor and Barthel conducted a government investigation of the dust concentration in the vicinity of the Differdange iron and steel complex (1956, published in 1958) (*Molitor, Barthel 1958*). Six passive samplers were placed for a period of about three months in a 2 km radius around the plant, allowing the amount of dust in g per m² per month to be calculated and a compositional analysis to be performed. Molitor and Barthel claimed that insoluble particles such as Fe2O3, SiO2, CaO and SO4 did not have harmful effects, regardless of particles sizes. However, pulmonary diseases like siderosis (caused by iron dust) were identified decades before this study was published (*Doig, Mclaughlin 1936*), indicating that this claim was incorrect even at the time of publication. Dust fractions below 0.03 mm (*inhalable* fraction, see ([section 3](#anchor-section-3)),) were observed in the samples, including silica, which indeed poses a risk for respiratory diseases and other health issues. The Differdange analysis further indicated that dust concentrations dropped rapidly as the distance from the factory increased, starting with 140 g/m²/month near the centre of pollution and falling to about 40 g/m²/month at a 2 km distance. With the decreasing dust mass, the iron content decreased as well, dropping from 75% to 38.4% (*Molitor, Barthel 1958*). These measurements once again show the high contribution of steelmaking to dust pollution levels in the Minett, especially near blast furnaces. However, the values measured by Molitor and Barthel cannot be compared directly to the simulation presented in our analysis, since the passive sampler was unable to capture fractions of dust below 5 µm (*Heyart 1958*); in addition, the measurement units and production site are not the same. The measured values in 1956 nevertheless seem to be far higher than the simulated ones, which indicates that the dust concentrations in our simulation are probably underestimated.

In 1966-1969, Barthel was again involved in dust measurements, this time commissioned by the municipal administration of Esch (9139636/XP9DGUVF). Barthel’s new observations were publicly released in 1972, a year marked by intense worldwide interest in environmental pollution problems – not least with the publication of the Club of Rome’s report *Limits to Growth* (*Buelens 2022*). Compared to the Differdange analysis, the number of measurement points was increased to 52 (spread over the entire surface area of the town), resulting in 16 samplers per km. This allowed for a more fine-grained analysis of the accumulated dust generated by multiple iron and steel complexes (Belval, *Terres Rouges* and Schifflange). The measurements were subsequently compared to the West German limit values for atmospheric dust pollution, which were a maximum of 0.42 g/m/day in urban zones and 0.85 g/m/day in industrial zones (9139636/XP9DGUVF). Over half of the measurement points were reported to exceed the West German dust limits for *urban* regions (34 in 1966-1967, 35 in 1967-1968 and 28 in 1968-1969), while several points even showed values above the *industrial* limits (9, 6 and 7 respectively). When compared to the simulation model, the measured values are significantly higher (dimensions of measurements in g/day and for the simulation in mg/month). The dust composition showed an iron oxide content of about 65%, varying with distance, indicating a clear link with the steelworks. Even though Barthel incorrectly stressed that the dust concentrations had no significant effect on human health, he did call for technical improvements that could bring the pollution levels down to the West German norm for industrial zones.

Lastly, in 1971, Christiane Conter wrote a dissertation on atmospheric pollution, based on measurements performed in 1970-1971 as part of an academic research project at the Belval plant (9139636/7BPU6L8S). Conter’s work clearly presented an environmental point of view, with a focus on various sources of pollution (steelworks, households and traffic). The dust samples at the Belval steel complex were specifically analysed regarding fluorine compounds, known for being released during various industrial processes and for their toxic effects on vegetation and animals. Sampling stations were placed near various points in the production chain; the average dust concentration measured was 6 g/m/day, which exceeded not only the West German legislative limits but also the measurements undertaken by Barthel in the years before. Just like Molitor and Barthel (Differdange, 1956-1957), Conter analysed dust composition in terms of soluble and insoluble particles. However, her specific focus on fluorinated compounds yielded no concrete results, as possible trace amounts were superimposed by the dust matrix. Additionally, the methods used (X-ray spectroscopy and electron microscopy) were not sensitive enough to detect fluorinated compounds (9139636/7BPU6L8S).

Despite the lack of comparability between the simulated values and the available measurements, our simulation allows us to isolate the dust pollution potentially generated by a single steelworks in the past and to understand how far it reached over time. From this point, the analysis could be extended to other industrial plants and other types of pollution, which would probably bring us closer to the historical measurements. At the same time, the lack of detail in these measurements, which obviously cannot be measured again, creates an opportunity for the use of modelling and simulation.

## Limitations and lacunae of the dust simulation

Throughout this research, we have presented different decisions taken during the process of simulation, validation and visualization of the data. These decisions simplify and reduce the complexity of the problem, but they have been made consciously and serve a specific purpose: to simulate industrial dust pollution from a single factory in a given period, based on historical data; above, we have presented the results of these decisions. This simulation can change perspectives on the past, e.g. with looking at the seasonal changes of wind directions and therefore changes in dust distribution (which is often omitted in historical literature). In future developments, we could modify the model variables (e.g. using data from other sources) or include new variables and use a different model (see ([section 8.4](#anchor-section-8-4)),). In any case, we have proven that data simulation based on historical data offers the option not only to recreate past situations, but also to isolate effects that would not be possible to analyse even with real measurements.

Despite these advantages, our simulation also has a number of limitations and gaps, to which we have already alluded in previous sections. Such limitations become relevant if we seek to understand the total pollution levels the analysed area were exposed to. First, not all dust emitting sources in the Belval region were considered; obviously, the steel industry was only one contributor to atmospheric pollution among many – albeit a very important one (*Metz 1972*, *Hoffmann 1974*, 9139636/EG7EKVXT). Pollution from households, industrial heating and traffic (motor vehicles and trains) accounted for some of the dust particles as well. Second, regarding the mathematical formula (1) used (presented in ([section 6](#anchor-section-6)),), a few parameters must be analysed critically. The choice of a Gaussian model in itself involves simplifications. The model assumes that the contaminants come unidirectionally from one point source (one of several chimneys) at a constant emission rate Q, with the wind direction always aligned in one axis, considering the time frame of one month (*Stockie 2011*, *Leelőssy, Molnár, Izsák, Havasi, Lagzi, Mészáros 2014*). This assumption does not cover intramonth variations and only considers one metallurgical plant (from a total of three in Esch alone). The model is not suitable for low wind speeds, and in terms of meteorological data only averages for Luxembourg City (the 10th and 20th of each month), which is about 20 km from Belval, were used. Since Gaussian plume models used in the calculation of atmospheric pollution usually consider the specific features of the surrounding (*Stockie 2011*), our formula could be extended to involve terrain information and a greater radius could be covered to better observe long-range effects. State-of-the-art Gaussian models like AERMOD, CTDM and ADMS try to extend the basic equation by including additional factors like a complex terrain (*Leelőssy, Molnár, Izsák, Havasi, Lagzi, Mészáros 2014*).

Another factor influencing the results is our use of US data from 1963 (*Schueneman 1963*) concerning average dust values for different steelmaking techniques and typical filter installation dates. Steelmaking and filter use vary between individual steel plants. The production data used covered only annual values; consequently, data on monthly production would make the simulation more precise. To better interpret the calculated dust values with regard to regulatory limit values and to determine a possible health effect, it would be useful to identify the dust fractions and pollutants contained therein. This is complicated, however, as historical dust samples have not been preserved and documents on measurements performed in the past (see 7.2) only study a small set of pollutants. Dust pollution values are usually standardised using temperature and pressure, which presents another limitation for interpretation. Lastly, the dust values identified using the model are technique specific (e.g. for Thomas steel) and do not relate to dust generation processes (e.g. sintering) used to set limit values for current EU regulations.

To summarise, the dust simulation of the Belval complex between 1911 and 1997 is just a starting point towards modelling the operation of a real-world process: the total generation and spread of pollution to which the inhabitants of Esch and the surrounding area were exposed. In ([section 8.4](#anchor-section-8-4)),, we offer a few possible ways of optimising the simulation in future research.

### Optimisation and improvement of the model

Some of the lacunae mentioned in ([section 8.3](#anchor-section-8-3)), can be improved, thereby opening possibilities for further research. Other emission types like traffic, heating and other industrial plants could be considered, as well as the terrain around the point sources. The overlap of multiple dust generating sources and the resulting plumes, however, involves the risk of making the visualisation too complex and therefore confusing. As we state above, the model and used parameters were chosen on purpose, to simulate an isolated phenomenon.

The model area could be expanded, and temperature and pressure data could be considered. All these changes would increase the complexity of the mathematical formula. The meteorological data for the years 1911-1948 could be digitised to access additional data such as the wind directions and speeds for all months. Moreover, subdividing dust particles into different pollutants and fractions would enhance accuracy, while the generation of dust for each individual ironmaking and steelmaking process could be an interesting parameter to analyse further (especially with regard to the health impact of dust). However, the latter extension of the simulation is at the limit of what is practically feasible, since past dust samples (or contemporary analyses) from the respective processes are required for a precise investigation of the dust, its fractions and its origins. For several short periods, a composition analysis of the dust particles was performed; for other periods, the amount of dust created by different processes in the plant was measured, as explained in ([section 8.2](#anchor-section-8-2)),. Using these data points is a possible way to extend the simulation, even if only for these specific years. Finally, it would be beneficial to look for average dust values produced by Luxembourg’s steel industry, monthly production data, filter installation dates and filter efficiency rates. Such data is most likely present in the corporate archives of ARBED, which are unfortunately not completely accessible for researchers. The optimisation possibilities outlined above would take our study beyond its initial scope.

## Conclusion

Air pollution has a long history: it is not only a problem of the past but also an issue affecting the present and the future. Especially in industrialised regions, atmospheric pollution is not only annoying; it can also be a dangerous companion of daily life. Dust particles in the respirable fraction pose the most worrisome threats to human health, as they can lead to lung diseases. In many parts of the world, the steel industry has contributed significantly to the total mass of airborne dust. Improvements in production techniques and the installation of filters, as well as legislative measures and economic crises, have influenced air pollution over the years.

Our analysis outlined the evaluation of dust production from a single plant in terms of plausibility and health effects. The simulated dust concentrations were compared to measurements and observations from the past, representing the ‘scientifically proven reality’ during a specific time period. For the simulation, a Gaussian plume model was used; the inserted parameters were analysed critically in terms of their limitations and possible improvements. Given the lack of availability of data regarding the dates of filter installations in Belval, secondary literature on the US case was used.

This research applied a modelling method widely used in applied sciences, using data from historical sources as the parameters of the calculation. One of the challenges of modelling and simulation is to find the right balance between complexity (and therefore precision) and interpretability. In this case, given the already added complexity of the interdisciplinary approach, we decided to use a simplified model, which can be a precedent for creating new ways of generating historical data. At the same time, it allows us to present evidence (albeit on just a fraction of the dust to which inhabitants were exposed) and to understand the impact on health in a specific historical context.

The decision to visualise the pollution as coming from just one chimney has important benefits, since the addition of multiple dust sources might overload the visualisation (in the latter case, it would no longer be possible to discriminate between the origins of the dust). Furthermore, it has never been possible to measure the isolated dust concentration of a single plant using samplers, as there are always other dust sources. In sum, our model can serve as a basis for studying atmospheric pollution released from one selected source and offers the potential to be extended by looking at other contributing factors. The data visualisation produced as the result of this research was used in the context of a public history project, making complex historical and scientific data accessible to the public.

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