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Entwicklung von Methoden zur Berechnung von Emissionen von Luftschadstoffen aus Bautätigkeiten und Baustellen

Development of Methods for the Generation of Emission Data for Air Pollutants from Building Activity and Construction Zones

von

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Kurzbeschreibung

In der vorliegenden Studie wird eine Verbesserung der Tier 1-Methodik zur Berechnung der Emissionen des Sektors Baustellen und Bautätigkeiten vorgeschlagen. Mit der Methodik können nach Quellgruppen differenzierte Abschätzungen der Emissionen durchgeführt werden. Als Aktivitätsdaten werden jährlich fortgeschriebene amtliche Statistiken verwendet. Die Methodik kann insbesondere für die deutsche Emissionsberichterstattung verwendet werden, sie ist aber auch für andere europäische Länder anwendbar und kann in das EEA Guidebook integriert werden.

Durch umfangreiche Literaturrecherche konnten zwei für den Tier 1-Ansatz geeigneten Berechnungsmethoden identifiziert werden. Dabei handelt es sich zum einen um eine US EPA-Methodik und zum anderen um ein niederländisches Verfahren zur Abschätzung von Emissionen aus Bautätigkeiten. Beide Methoden decken einen Großteil der relevanten Bautätigkeiten ab.

Eine Analyse der beiden Methoden hat gezeigt, dass die US EPA-Methodik für die Emissionsberechnung für Deutschland und Europa der niederländischen Methodik vorzuziehen ist.

Unter Anwendung der empfohlenen US EPA-Methodik wurden für Deutschland die Emissionen für die Zeitreihe 1990 bis 2014 berechnet. Des Weiteren wurde die Methodik für die Integration in das EEA Guidebook aufbereitet. Das entsprechende EEA Guidebook Kapitel ist in einem separaten Dokument zusammengefasst.

Die Unsicherheit der berechneten Emissionen ist deutlich höher als die für die meisten anderen Feinstaubquellen. Eine weitere Verbesserung der Abschätzung von Emissionen aus Bautätigkeiten über die Verwendung der hier empfohlenen US EPA-Methode hinaus kann nur durch umfangreiche Messkampagnen an Baustellen in verschiedenen Regionen Europas erzielt werden.

Abstract

This document describes emission calculation methods for the construction sector. The most suitable emission estimation method for Germany is identified and guidance for the application of this methodology for other European countries is provided. The new method is a Tier 1 method that should replace the current Tier 1 methodology in the EEA Guidebook.

A literature survey revealed, that two methodologies exist, that can be classified as a Tier 1 approach, namely the US EPA methodology and the Dutch methodology. These two methodologies cover the entire range of construction-related sources and do not require detailed activity data.

An evaluation of both available Tier 1 methods in this study shows, that the soil dust contribution might have been underestimated using the Dutch methodology. The recommended Tier 1 method is therefore the one proposed by the US EPA.

Using the US EPA Tier 1 methodology the emissions for Germany from 1990 until 2014 were estimated. Guidance how to apply the identified methodology for European countries besides Germany is given in a separate document that is meant to replace the current section on construction emissions within the EEA Guidebook.

All emission literature dealing with construction activities states that the estimated emissions by the construction industry are only a first order quantification of the actual emissions. Uncertainty is generally considered to be much higher than for most other sources of primary PM.

To develop a methododolgy, that improves the results of the recommended US EPA methodology, an extensive campaign would be needed, that measures and monitors PM emissions at major and minor construction sites at various locations across Europe over the whole duration of the activity.

Zusammenfassung

In der vorliegenden Studie wird eine Verbesserung der Tier 1-Methodik zur Berechnung der Emissionen des Sektors Baustellen und Bautätigkeiten vorgeschlagen. Mit der Methodik können nach Quellgruppen differenzierte Abschätzungen der Emissionen durchgeführt werden. Als Aktivitätsdaten werden jährlich fortgeschriebene amtliche Statistiken verwendet. Die Methodik kann insbesondere für die deutsche Emissionsberichterstattung verwendet werden, sie ist aber auch für andere europäische Länder anwendbar und kann in das EEA Guidebook integriert werden.

Seit längerem wird vermutet, dass Bautätigkeiten einschließlich Abriss von Gebäuden eine sehr wichtige Quelle vor allem für Feinstaubemissionen sind. Die verfügbaren Abschätzungen weisen daraufhin, dass Baustellen und Bautätigkeiten einen erheblichen Anteil an den PM10-Emissionen haben, insbesondere durch die Verarbeitung und Lagerung von Baustoffen während des Baus, der Renovierung und des Abrisses von Gebäuden. Da Gebäude sich in den allermeisten Fällen in bebauten Gebieten befinden, also da, wo Menschen wohnen und arbeiten, führen Emissionen aus Bautätigkeiten zu einer hohen Exposition und damit zu vergleichsweise hohen Gesundheitsrisiken. Die Bewertung der derzeitigen Belastung der Bevölkerung durch Luftverschmutzung und die Erarbeitung von Luftreinhalteplänen setzt die Kenntnis der Emissionen aus allen wichtigen Quellen voraus, also auch aus Baustellen und Bautätigkeiten.

Die Quellgruppe Bautätigkeiten verursacht neben den diffusen Staubemissionen auch Emissionen weiterer relevanter Luftschadstoffe wie z.B. NO_X, Ruß und CO_2, die auf Verbrennungsvorgänge zurückzuführen sind (Emissionen durch Baumaschinen und Geräte, Wärmebehandlung von Baumaterialien). Auch die aus der Produktanwendung resultierenden NMVOC-Emissionen (z.B. Anwendung von Farben, Lacken oder Lösemitteln) sind dabei als relevant anzusehen. Allerdings existieren für die oben genannten Luftschadstoffe erprobte Berechnungsmethoden, die bereits an anderer Stelle in die Emissionsberichterstattung eingeflossen sind. Aus diesem Grund betrachtet diese Studie nur die diffusen Staubemissionen, die vor allem durch mechanische Prozesse verursacht werden.

Durch umfangreiche Literaturrecherche konnten zwei für den Tier 1-Ansatz geeignete Berechnungsmethoden identifiziert werden. Dabei handelt es sich zum einen um eine Methodik der US EPA, zum anderen um ein niederländisches Verfahren zur Abschätzung von Emissionen aus Bautätigkeiten. Beide Methoden decken einen Großteil der relevanten Bautätigkeiten ab.

Der Großteil weltweit existierender Informationen und Methoden zur Berechnung von diffusen Staubemissionen aus Bautätigkeiten ist auf die US EPA-Methodik zurückzuführen. Die ersten Arbeiten an der Ermittlung sektorspezifischer Emissionsfaktoren für diffuse Staubquellen begannen in den USA bereits in den 1970er-Jahren. In den 1980er- und 1990er-Jahren wurde eine Reihe von Messkampagnien an Großbaustellen in Las Vegas und in Kalifornien durchgeführt. Die Messergebnisse sind später in die aktuelle Top-down Tier 1 US EPA-Methodik eingeflossen. Ende der 1990er-Jahre wurde die EPA-Methodik auf Basis von gemessenen Emissionsfaktoren überarbeitet. Die neue Methodik ermöglicht die Berücksichtigung regionaler Unterschiede des Klimas (Niederschlagsmenge, Verdunstung) und der Bodenbeschaffenheit (Schluffgehalt, Bodenfeuchte). Somit kann die aktuelle Methodik auch in weiteren Regionen des Landes angewendet werden. Der Einsatz der US EPA-Methodik erfordert vor allem Angaben über die durch Bautätigkeiten betroffene Fläche. Als Aktivitätsdaten werden baurelevante Daten wie beispielsweise die bebaute Grundfläche oder der Typ des errichteten Gebäudes, Gesamtkosten, Anzahl der Gebäude oder Streckenlänge (bei Straßen) herangezogen.

Andere Vorgehensweise zur Berechnung von baubedingten Emissionen bietet eine Berechnungsmethodik aus den Niederlanden. Dieser Ansatz wurde von der HASKONING Company im Jahr 2000 (Kimmel, 2000) entwickelt. Er basiert zum Teil auf der gemessenen Exposition der Beschäftigten der Bauwirtschaft mit den baubedingten Stäuben. In die Methodik sind zum Teil auch die US EPA Emissions-

faktoren eingeflossen (bei der Staubaufwirbelung durch Baustellenverkehr). Der niederländische Ansatz dient als Grundlage für die bisherige Tier 1-Methodik im EEA Guidebook. Als Aktivitätsdaten werden die fertiggestellte Fläche der Gebäude (Wohnfläche oder Bürofläche) oder die Beschäftigtenzahlen der jeweiligen Baubrache verwendet.

Eine Analyse der beiden Methoden hat gezeigt, dass die US EPA-Methodik für die Emissionsberechnung für Deutschland und Europa der niederländischen Methodik vorzuziehen ist. Im Vergleich zur EPA-Methode deckt diese Methode zwar den Großteil der Emissionen aus den Ausbauarbeiten ab, unterschätzt anderseits die Staubemissionen durch Erdarbeiten wie Bodenaushub und Erdbewegungen. Das niederländische Verfahren wurde auch noch nicht durch Messungen validiert. Die empfohlene US EPA Tier 1-Methodik wurde für die USA entwickelt und bisher noch nicht außerhalb der USA angewendet. Die US EPA-Methode liefert in der Regel deutlich höhere Emissionen als die Methode von Kimmel und ist mit hohen Unsicherheiten behaftet.

Die US EPA Tier 1-Methode kann für die Berechnung der Emissionen aus folgenden Bereichen der Bauwirtschaft eingesetzt werden:

- Wohnbau: Ein- / Zweifamilienhaus,
- Wohnbau: Mehrfamilienhaus,
- Nichtwohnbau,
- Straßenbau.

Die EPA-Emissionsfaktoren gelten allerdings nur für Neubauprojekte angewendet werden. Abriss und Renovierungsarbeiten sind durch diese Methode nicht abgedeckt.

Unter Anwendung der empfohlenen US EPA-Methodik wurden für Deutschland die Emissionen für die Zeitreihe 1990 bis 2014 berechnet. Die PM10-Gesamtemissionen aus Bautätigkeiten in Deutschland im Jahr 2014 liegen bei etwa 7,6 kt. Den größten Anteil an den Gesamtemissionen liefert der Subsektor Nichtwohnbau mit etwa 4,1 kt PM10. Straßenbau verursacht etwa 2,3 kt und der Wohnbausektor etwa 1,2 kt PM10. Der Beitrag der baubedingten PM10-Emissionen in Deutschland an den Gesamtemissionen von PM10 liegt bei 3,6%.

Obwohl die US EPA-Methode mit hohen Unsicherheiten behaftet ist und nicht explizit für die Anwendung in gemäßigten Klimazonen Europas entwickelt wurde, sehen die Autoren dieser Studie in der empfohlenen EPA-Methodik eine erhebliche Verbesserung der Emissionsberechnung gegenüber der bisherigen EEA Guidebook Tier 1-Methodik. In dieser Studie werden Möglichkeiten zur Anpassung der Emissionsfaktoren an die für Europa typischen Bedingungen (Klima, Bodenbeschaffenheit) aufgezeigt, mit den vorgeschlagenen Anpassungen kann die US EPA-Methode auch für Deutschland und Europa angewandt werden.

Eine weitere Verbesserung der Abschätzung von Emissionen aus Bautätigkeiten ist nur möglich, wenn umfangreiche Messkampagnen an Baustellen in verschiedenen Regionen Europas durchgeführt werden.

Summary

This document describes emission calculation methods for the construction sector. The most suitable emission estimation method for Germany is identified and guidance for the application of this methodology for other European countries is provided. The new method is a Tier 1 method that should replace the current Tier 1 methodology in the EEA Guidebook.

It has long been recognized that the construction of infrastructure and buildings constitutes an important source of fugitive particulate matter (PM) emissions. Frequently, elevated ambient PM10 concentrations are observed at and around construction works. A significant part of the construction activities takes place in urban and other densely populated areas. Consequently a large number of people may be exposed to PM emitted from construction activities.

Besides being a source of fugitive PM emission, construction activities may emit other pollutants as well. This mostly concerns combustion products such as NO_X, soot and CO_2, as well as fugitive NMVOC emissions resulting from product uses. In emission inventories however all combustion and product use emissions are estimated elsewhere, as either a part of emission by mobile machinery or as a part of solvent and product use emission. This study considers therefore only fugitive PM emissions.

There are basically two methodologies that could be classified as Tier 1 approach, namely the US EPA methodology and the Dutch methodology. These two methodologies cover the entire range of construction-related sources and do not require detailed activity data.

The vast majority of all available information on fugitive PM emission by construction activities originates from the United States. Work started there in the 1970s with the development of emission factors for specific construction-related fugitive dust sources, such as earth moving activities. In the 1980s and 1990s dust measurements downwind of large construction sites took place in Las Vegas and California and the results have been the basis for EPA's current top-down Tier 1 methodology for construction emissions. This methodology was developed and refined in the late 1990s and has been adapted for use for other regions of the US by giving the possibility to correct for climatic and soil differences. As input data, the affected area for a number of major types of construction is needed.

A rather different approach was followed by the HASKONING Company in 2000 (Kimmel, 2000). It is based on inverse modelling of emissions from occupational dust exposure data for dust sensitive professions in the construction industry. It also partially relied on general EPA emission factors for vehicular dust resuspension and a crude estimation of vehicular movements. This methodology was the basis for the previous Guidebook Tier 1 emission factors. The method only requires basic activity data, like total floor area constructed or number of active workers for major branches in construction.

An evaluation of both available Tier 1 methods in this study has shown that the soil dust contribution might have been underestimated by the aforementioned Dutch approach. According to their method the majority of the emissions are caused by specific building and finishing activities, mostly indoor, rather than soil dust. This method was however never backed by any direct emission measurements and there is no documentation available in English.

The recommended Tier 1 method is therefore that by the US EPA, after adjusting the emission factors to the conditions in Europe. It gives, in general, considerably higher results than the method by (Kimmel, 2010).

All emission literature dealing with construction activities states that the estimated emissions by the construction industry are only a first order quantification of the actual emissions. Uncertainty is generally considered to be much higher than for most other sources of primary PM.

The US EPA Tier 1 method only considers new construction (including site preparation). Renovation or demolishing without any significant new construction is not covered and there are no other emission factors available for demolition activities only.

The US EPA Tier 1 emission estimation approach for construction activities distinguishes four main types of construction:

- Residential housing, single-family or two-family,
- Residential housing, apartments,
- Non-residential housing,
- Road construction.

Using the US EPA Tier 1 methodology the emissions for Germany from 1990 until 2014 were estimated. The total PM10 emission from construction in Germany in 2014 is around 7.6 kt. The highest contribution is made by the construction of non-residential buildings (4.1 kt). Road construction contributes for around 2.3 kt and the construction of various types of housing about 1.2 kt PM emissions. The share of construction PM10 emissions to the total PM10 in Germany is around 3.6%; for PM2.5 it is far lower (about 1%).

Although highly uncertain and not originally developed for use in temperate regions in Europe, we propose the EPA Tier 1 methodology to be adopted for estimating construction emissions in Europe. This study investigated several possibilities to correct the results for typical European conditions. Because the conditions in Europe may be very different from the arid southwest of the US it is possible that using the US EPA Tier 1 method for Europe is stretching its applicability and representativeness beyond the limits. However, the only alternative would be an extensive campaign to actually measure and monitor PM emissions at major and minor construction sites at various locations across Europe, over the whole duration of the activity.

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List of Abbreviations

av.	average
BC	Black Carbon
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
BMVI	Bundesministerium für Verkehr und digitale Infrastruktur
CLRTAP	Convention on Long-range Transboundary Air Pollution
CEPMEIP	The Co-ordinated European Programme on Particulate Matter Emission Inventories, Projections and Guidance
EEA	European Environment Agency
EF	Emission Factor
GHG	Greenhouse Gas
IAQM	Institute of Air Quality Management
MRI	Midwest Research Institute
NL-ER	Netherlands Emission Registration system
NMVOC	Non-Methane Volatile Organic Compounds
PM	Particulate Matter
TREMOD	Transport Emission Model
TSP	Total Suspended Particles
UNECE	United Nations Economic Commission for Europe
UK	United Kingdom
US EPA	United States Environmental Protection Agency
WRAP	Western Regional Air Partnership

1 Background

Although it has long been recognized that road and building construction activity constitutes an important source of fugitive particulate matter (PM) emissions, only limited research has been directed to its characterization. Construction and demolition activities may emit also other pollutants like NO_X, diesel particulate matter, GHGs and NMVOCs. In emission inventories (including the German National Inventory), construction-related NO_X, exhaust PM and GHG emissions are estimated as a part of the emissions from the source category mobile machinery and vehicles.

Building and construction activities are likely to contribute to the emissions of fugitive particulate matter, mostly due to storage and handling of building materials when constructing a new building, renovating a building, or demolishing an old building. Since the majority of buildings are located in urban areas, most of construction works take place in this area as well. Consequently, a large number of people may be exposed to PM emitted from construction activities. To assess the impact of these activities and to compare its impact to that of other urban activities such as road transportation and residential heating, a good understanding of the magnitude of the emissions is a key first step.

1.1 International perspective

Under the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP), European countries have committed themselves to annual reporting of air pollutants emitted through anthropogenic activities. The annual reporting of emissions is a key part in monitoring the progress of each country towards the targets set by the CLRTAP Gothenburg Protocol, which sets relative ceilings for the reduction of air pollutants. Additionally, the EU National Emission Ceilings Directive sets targets for emission ceilings for each country, and in assessing compliance with the Directive the national emission inventories submitted to CLRTAP play a crucial role.

The EMEP/EEA Guidebook has been last updated in 2014. In the reporting structure, there is a specific NFR sector for reporting emissions from construction: "2.A.5.b: Construction and demolition" (changed from 2.A.7.b used before 2015). Additionally, there is a chapter in the Guidebook dedicated to this sector which provides Tier 1 emission factors for the emissions of TSP, PM10[1] and PM2.5[2] from construction and demolition activities. These emission factors are based on the CEPMEIP study[3] which was one of the first European-wide emission inventories for particulate matter. For construction activities CEPMEIP in turn relied on the methodology used in the Dutch Emission Registration (NL-ER, 2015).

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1 PM10 particles with a diameter of 10 micrometres or less

2 PM2.5 particles with a diameter of 2.5 micrometres or less

3 Visschedijk, A.J.H., Pacyna, J., Pulles, T., Zandveld, P. and Denier van der Gon, H., 2004. Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP). In: Dilara, P. et al. (eds.), Proceedings of the PM emission inventories scientific workshop, Lago Maggiore, Italy, 18 October 2004. EUR 21302 EN, JRC, pp. 163–174.

2 Objective

This study aims at identifying and applying the most suitable emission estimation method for Germany from literature and provides guidance for application of this methodology for other European countries. Guidance on how to apply the identified methodology for European countries besides Germany will be given in a separately written special EEA Guidebook chapter that is meant to replace the current section on construction emissions. The new method is a Tier 1 method that is based on a limited set of easily obtainable activity data, it should replace the current Tier 1 methodology in the Guidebook[4].

Using the Tier 1 methodology, a time series of PM emissions from this sector for Germany is calculated for the period 1990-2014.

2.1 Relevant construction activities and pollutants

The construction sector is a diffuse sector, with many different individual sources of emission, which could potentially all be estimated separately, resulting in a rather detailed methodology that requires many types of activity data.

The following dust sources are typical for construction activities: Earth moving, equipment movement, land clearing and demolition, mobile equipment for crushing debris, loading, unloading and hauling of materials (e.g. on unpaved temporary roads), specific construction activities like concrete, mortar and plaster mixing, drilling, milling, cutting, grinding, sanding, welding, sandblasting activities, various finishing activities, track out of dirt on paved roads and resuspension and windblown dust from temporary unpaved roads and bare construction sites. The emissions are largely of mineral composition with soil dust typically comprising a big part.

Methodologies to estimate fugitive PM emissions from construction activities include the resuspension of soil dust by hauling traffic as important component. Resuspension by road transport as a whole is also estimated by other methodologies and here lies a danger of double counting. However literature suggests that resuspension on construction sites by unit of activity is about an order of magnitude higher than ‘normal’ traffic-induced resuspension (even on unpaved roads) so these emissions must be estimated separately for construction. Thus the selected Tier 1 methodology will include resuspension of soil dust by hauling vehicles.

Construction activities usually bring about the use of motorized mobile machinery, of which exhaust emissions of CO_2, NO_X and PM also contribute to air emission at the site, especially to finer sized aerosol. In this study the emission estimation emphatically excludes exhaust emissions, as this type of emission is fully covered by other emission estimates already in place (e.g. by the TREMOD model in Germany). NMVOC emissions by product use (like paint and construction foam) also occur at construction sites but these emissions are already covered by the methodology to estimate solvent/product use emissions and are disregarded and excluded in this study as well. As a result of the above this study only considers fugitive dust emissions (TSP, PM10 and PM2.5).

4 For the new federal states of Germany the statistics for building construction is available from 1993 onwards.

3 Methodology

3.1 Analysis of the existing methodologies for the emission calculation for construction activities

3.1.1 Literature investigation

To identify a reliable methodology for estimating fugitive PM emission from construction activities for Germany and Europe a large body of literature was explored. This literature review has led to the following conclusions:

- 95% of the original literature on dust emissions from construction originates from the United States (US). Work started in the 1970s with the development of emission factors for specific construction-related fugitive dust sources, such as earth moving activities. The list of emission factors has been extended steadily since then and nowadays forms the basis for EPA's more detailed bottom-up tier 2 methodology for estimating fugitive dust emissions from construction emissions.
- In the 1980s and 1990s dust measurements downwind of large construction sites took place in Las Vegas and California over the full construction project duration and the results have been the basis for EPA's current top-down Tier 1 methodology for construction emissions. This Tier 1 methodology was developed and refined in the late 1990s and has been adapted for use in other regions of the US. It requires only basic parameters as activity data.
- In the mid-2000s two articles presenting new measurement results for construction sites appeared, both considering key contributing sources to construction emissions. (Kinsey et al., 2004) dealt with dust emission from vehicular construction mud/dirt carryout while (Muleski et al., 2005) concentrated on earth moving activities in road building out of a number of other considered sources. PM10 emission factors were derived that required detailed activity data on for instance vehicular movement. No link was made with the existing EPA Tier 1 methodology but results are not believed to disagree particularly. Both articles concluded that the PM2.5 content of fugitive PM10 emission was low (1–10%).
- A rather different approach to estimating fugitive construction emissions was followed by the HASKONING Company in the late 1990s in order to develop a methodology for the Dutch Emission Registration. It relied partially on a combination of earlier EPA emission factors for vehicular re-suspension on dust borrowed from other industries and a simple estimation of vehicular movements, and partially on inverse emission flux modeling based on occupational dust exposure data for various métiers in construction and finishing activities. The latter approach can be considered truly different from any of the US EPA methods. The Dutch methodology was the basis for CEPMEIP and the old construction emission factors in the EEA Guidebook.
- Although often giving useful and illustrative applications, most other literature is basically a reiteration of US EPA methodologies adding little to no additional new data. The EPA Tier 1 and 2 methodologies (although developed for the US) are used worldwide.

The full list of identified useful literature can be found in Appendix 7.6.

3.1.2 Identification and comparison of methodologies used in Europe for estimating PM10 emissions from construction activities

For a number of countries the project team has surveyed the methodologies used to estimate construction emissions when available. Methodological reports underlying the emission data submissions under international reporting obligations/commitments have been used for this. About half of the European countries appear to make some sort of estimate for construction-related PM10 emissions (see Table 1 in which the results are summarized and compared).

Table 1: Identification and brief comparison of methodologies used in Europe

Country	Used Methodology	Used Emission Factor	Share of PM2.5 on PM10
Norway	Norway uses PM10 emission factors based on an older French emission factor evaluation by CITEPA	0.152 ton PM10/1000m² floor area/year	34%
France	France uses an older AP-42 TSP emission factor (1995) for dwellings and the CEPMEIP/Guidebook default TSP emission factor for utilities with a PM10 and PM2.5 content according to US EPA	0.108 ton PM10/1000m² floor area/year (dwellings); 0.022 ton PM10/1000m² floor area/year (utilities)	33%
United Kingdom	The UK uses the current EPA Tier 1 emission factor, presumably corrected for precipitation/moisture and soil silt content	0.00715 ton PM10/1000 m² disturbed area/year	10%
Sweden	Sweden uses the CEPMEIP default PM10 factors	0.11 ton PM10/1000m² floor area/year (dwellings) and 0.061 ton PM10/1000 m² floor area/year (utilities)	10%
Poland	Poland uses the Guidebook default emission factor (version 2009) for PM10	0.0812 ton PM10/1000m² floor area/year	10%

Most of the countries in Europe that estimate construction emissions appear to use the old EEA Guidebook Tier 1 methodology or a predecessor of it. Emission factors for PM10 center around 0.1 ton PM10/1000m^2/year (floor area) with minor deviations up- or downwards. Only the UK currently uses the US EPA Tier 1 methodology. It is difficult to compare the used emission factors between the UK and the other countries, as the emission factors are rated to different activity parameters (constructed floor area vs. a combination of affected area and duration) that are likely correlated but not linearly dependent.

Apparently all countries succeeded in estimating the required activity data, presumably from national sources as Eurostat only gives the annual number of active workers per branch of the construction industry (10 in total) and the total monetary revenue of the construction industry.

3.2 Discussion and selection of methodologies

As is the case for many sources of fugitive dust, developing a reliable methodology to estimate emissions from construction activities forms a considerable challenge and results are often very uncertain. This is stressed in almost all relevant literature. There is a large variety of different activities involved in construction and the conditions under which these occur are highly variable. All emission literature states that the results are only a first order quantification of the actual emissions and the uncertainty is high. In the following section it will be motivated which methodology is considered best for application for Germany.

There are basically only two methodologies that could be classified as a Tier 1 approach, available worldwide, being the US EPA methodology and the Dutch methodology. These two methodologies cover the entire range of construction-related sources and do not require detailed activity data. There are many more emission factors for specific construction-related sources available from literature (e.g. from US EPA's AP-42 document) but these are part of a detailed bottom-up inventory of emissions that require highly detailed and sometimes difficult to acquire activity data and would therefore not qualify as a Tier 1 approach.

3.2.1 US EPA Tier 1 methodology

Although several useful literature sources have been identified, in the end only in the United States actual measurements aiming at quantifying the total emission of all construction-related sources have taken place. In no other country any representative measurements that cover the entire range of sources within the whole sector have been conducted. The results of the US measurements at actual construction sites form the basis for the current EPA Tier 1 methodology for construction emissions. This methodology consists of overall emission factors for a limited number of construction types, which must be multiplied by the area affected by the construction project and the project duration.

The measurements underlying the EPA methodology took place at several large sites in California and in Las Vegas, where there is a dry climate and geological dust is typically a large contributor to ambient PM10 levels. Although no quantitative estimates for contributions are given by the EPA, it is stated that during these measurements, for construction-related sources suspended geological dust was the main contributor. Other construction-related sources including those discussed in the introduction of this document are covered as well but their combined contribution over the entire construction period was found to be low compared to soil dust. The current EPA Tier 1 method distinguishes multiple emission factors for several major types of construction. The methodology is documented in full in (WRAP, 2006).

In order to adapt the method for use for the rest of the US where climatic conditions and soil characteristics may be very different, a method for correction has been developed by the EPA, by which the user can modify key parameters like soil moisture content and soil particle size.

3.2.2 Dutch methodology

For use in the Dutch Emission Registration a methodology for estimating emission in the construction sector was developed in the year 2000 (Kimmel, 2000). Like the EPA method it aims to cover all relevant construction-related sources. Basically two approaches have been followed by (Kimmel, 2000), one approach using EPA emission factors for specific sources borrowed from other industries and the other one by inverse modeling of emissions based on known or estimated occupational dust exposure data for construction workers.

Resuspension by hauling activities is estimated using, in general, EPA emission factors for unpaved roads, which may, as discussed earlier, be too low for the typical situation at a construction site. In addition, the activity data which are needed to apply these emission factors (VKT, vehicle kilometers travelled for materials hauling) were not available for the Netherlands as a whole and had to be estimated. This estimate may have been too conservative in hindsight as the total soil dust contribution was estimated to be low in absolute sense, accounting for only one quarter of the total emission. In this way the Dutch methodology has a fundamentally different outcome than the EPA methodology, in which geological dust dominates, even with correction for temperate climatic conditions.

In the Dutch methodology the largest contribution comes from outdoor building and indoor finishing activities (the other half and one quarter of the total emission, respectively). This estimate is based on occupational dust exposure data for various types of work and the number of workers for each type of profession (available from Dutch statistics). Note that in the EPA Tier 1 methodology these sources are also included but not mentioned there as typically being major contributors compared to soil dust emissions.

The contribution of indoor and outdoor demolition and windblown dust were estimated to be very low in the Dutch methodology, in addition to being highly uncertain.

Because the emission of geological dust is estimated to be very low by the Dutch methodology it is believed to lead to an underestimation of fugitive dust emissions from construction. In addition detailed and very specific activity data (e.g. on vehicular movements) are needed to estimate geological dust emission. Appendix 7.1 describes the method in detail.

3.2.3 Selection of methodology

The Dutch methodology has been the basis for the CEPMEIP inventory and the older emission estimation methodology currently described in the EEA Guidebook for fugitive emissions from construction. For the Guidebook the Dutch total is extrapolated for use in other countries based on the total amount of floor area constructed (a primary indicator of construction activity and usually available from national statistics). An alternative approach not pursued in the Guidebook would be to extrapolate based on the number of construction workers. For illustration and comparison purposes this has been done in Appendix 7.2. Based on the number of workers in the Netherlands in the various construction sectors for the reference year of the Dutch methodology and the current number of workers in Germany, an indicative calculation for Germany based on the Dutch methodology has been made for comparison (see Appendix 7.2 and section 5.2).

There are, however, some serious drawbacks to the Dutch methodology as it requires relatively detailed activity data (among others vehicle kilometers travelled (VKT) for hauling and an inventory of workers in different construction métiers) and is for the largest part based on engineering considerations and not direct emission measurements, which may make it less realistic than the EPA Tier 1 method. Moreover there are indications that in the Dutch way to estimate the VKTs, as well as the resuspension emission factors may lead to underestimations.

The other available Tier 1 method is the one proposed by the US EPA. It is based on actual measurements and requires just basic activity data, namely the affected area and the construction duration. It can be argued that the conditions under which the US measurements have been taken are not representative for Germany but it can be corrected for climatic and soil conditions. This makes the Tier 1 method in theory suitable for regions other than the US (for instance in Europe) but one should be aware that in general the further away the reigning conditions are from those of the original measurement, the more uncertain the results will be. In Germany both the average soil silt content (the fraction of the soil that is most dust sensitive) and soil moisture content are very different from those in California and Las Vegas and even many other parts of the US.

Although highly uncertain and not developed for use in temperate regions in Europe we propose to adopt the EPA Tier 1 methodology for estimating construction emissions in Europe, in which we will use all possibilities to correct the results to typical European conditions. Because the conditions in Europe may be very different from the arid southwest of the US it is possible that using the US EPA Tier 1 method for Europe is stretching its applicability and representativeness beyond the limits. However, the only alternative would be an extensive campaign to actually measure and monitor PM emissions at major and minor construction sites at various locations across Europe, over the whole duration of the activity.

It is not fully clear from EPA's methodology documentation to what extend demolition activities are included. The method claims to include all construction-related activities and therefore demolition of existing structures as a part of the process of new constructing should be covered. Demolition that is not directly part of any new construction is not included by EPA's Tier 1 method. In the Dutch methodology demolition activities are estimated to only make a small contribution, primarily because demolition usually occurs in a short period of time. The Dutch emission estimate is however very uncertain but there are no emission factors available from the US EPA specifically for demolition to validate the Dutch estimate. Extrapolation of the Dutch estimate for demolition activities to Germany suggests a German contribution of only about 50 tons of PM10, which led to the decision not to include demolition as a separate activity. In addition, renovation of existing buildings (without any significant new construction) is also not included.

4 Emission calculation

As already described in section 3.2, the EPA Tier 1 methodology is considered the most suitable approach for estimating emission from construction activities in Germany and Europe. Based on this methodology the emissions for Germany from 1990 until the latest reporting year 2014 were estimated.

The EPA approach was applied for the following construction activities:

- Residential buildings
- Non-residential buildings
- Road construction

In the following chapter the applied methodology is described along with the emission factors and activity data used. Step-by-step calculations of the emissions of TSP, PM10 and PM2.5 are provided in a separate Excel file.

The EPA methodology consists of the following four main calculation components:

- Emission factor
- Affected area
- Conversion factor
- Correction factor

The ***emission factor*** reflects the amount of emitted pollutant per unit of affected area and time. The EPA emission factors are applicable only to new construction. Renovation activities involving no new construction are not considered.

The ***conversion factor*** expresses the area of land affected by the construction of one unit (e.g. building, house, or road section). For the estimation of conversion factors for the different types of buildings the information about footprint of a building is required. The ***footprint*** of a building reflects the site area that it occupies.

The ***affected area*** reflects the area of land affected by construction activities beyond the footprint of a building. Table 2 shows EPA-Tier 1 emission factors and typical calculation parameters as used by the US EPA for the construction sector in the US.

In a twostep approach, first uncorrected emissions are calculated. Then the country-specific conditions (soil moisture, silt content, and control efficiency) for Germany are accounted for and ***correction factors*** for Germany are estimated and applied as described in chapter 4.6.

It is assumed, that the construction emission factors shown in the sections 4.1, 4.2 and 4.3 include the effects of typical control measures such as routine watering, which is very common during dry periods. A dust control effectiveness of 50% (time averaged control efficiency) is assumed for these measures (WRAP, 2006). If watering is not applied the emission factor should be doubled to more accurately reflect the actual emissions (WRAP, 2006).

There are no data for Germany about the implementation of emission reduction techniques or emission regulation limits for fugitive dust from construction sites. The urban administrations publish information sheets on how to reduce dust emission, waste and noise from the construction sites. No information on the implementation of these control measures is available. For this reason emissions factors are kept constant between 1990 and 2014.

Table 2: Tier 1 emission factors and typical calculation parameters as used by the US EPA (WRAP 2006)

	One-family house	Two-family house	Apartments	Non-residential	Road construction
Emission factor (PM10) in short tons/acre-month (not corrected)	0.032	0.032	0.11	0.19	0.42
Conversion factor	Footprint is 1/4 acre/building; area affected is five times the footprint	Footprint is 1/3 acre/building; area affected is four times the footprint	Footprint is 1/2 acre/building; area affected is three times the footprint	1.5 acres/million dollar spent	7.9-15.2 miles to acres 11.4 miles to acres (average)[5]
Duration of construction in month	6	6	12	11	12-18

4.1 Residential Buildings

Residential construction emissions will be calculated for three basic types of residential construction:

- Single-family houses
- Two-family houses
- Apartment buildings

The emissions from construction of residential buildings are calculated using the following formula:

$$EM = EF * B * f * m$$

EM ... emission of the specified pollutant (kg)

EF ... emission factor of this pollutant, not silt/moisture corrected (kg of emitted pollutants/m^2 affected area/year)

B ... number of buildings constructed (number of new buildings)

f ... conversion factor (area of land affected by construction activities per building)

m ... duration of construction activity (year)

The conversion factor (f) reflects the area of land affected by construction activities per building. The affected area is a product of the footprint of the building and factor of 2 because for Germany it is

5 Estimation of conversion factor depends on different road structure

assumed that for one single-family houses the affected area will be twice the footprint area of the house. For a two-family house the affected area is assumed to be 1.5 times the footprint area and for apartment buildings a factor of 1.3 is adopted.

The current average footprint for a single-family house in Germany is about 150 m^2, for a two-family house it is around 250 m^2 and for an apartment building it is 450 m^2. The average footprint for different types of residential buildings was derived from analysis of construction projects in Germany. The used references for the estimation of average footprint for the residential construction sector are given in Appendix 7.3.

To estimate the trend in the footprint development for the period 1990 to 2013 the evolution of the usable area in Germany was assumed. The duration of construction of a new one-/two-single-family house is assumed to be 6 months. For apartments a duration of 9 months is assumed. The dust-intensive processes typically occur in the beginning of the construction (e.g. earthmoving activities). Table 3 and Table 4 show the used activity data and emission factors.

Table 3: Activity data for estimating the emission for residential buildings

Parameter	Available statistics	
	Germany	Data quality
Number of new houses constructed	Bauen und Wohnen, lange Reihe, Kap.10.1 (Destatis, 2014a)	sufficient; for new federal states data available from 1993 onwards
Usable area in m^2	Bauen und Wohnen, lange Reihe, Kap.10.1 (Destatis, 2014a)	sufficient; data available from 1993 onwards

Table 4: Emission factors for emission calculation for residential buildings

Pollutant	Emission factor value		Unit[6]	Reference
	Single-/Two-family house	Apartments		
TSP	0.2869	0.9863	kg/m^2/year	WRAP 2006
PM10	0.0861	0.2959	kg/m^2/year	WRAP 2006
PM2.5	0.0086	0.0296	kg/m^2/year	WRAP 2006

4.2 Non-residential construction

Non-residential construction includes building construction (commercial, industrial, institutional, governmental) and also public works. For the non-residential sector the EPA uses an approach based on money spent on construction to estimate the affected area. A completely different cost situation of construction in Germany argues against this approach. For this reason, the same approach as for residential construction (estimating affected area from the building footprint area) is preferred.

6 All values have been converted from contractor to usual standard units.

The emissions from construction of non-residential buildings are calculated using the following formula:

$$EM = EF * B * f * m$$

where

EM	...	emission of the specified pollutant (kg)
EF	...	emission factor of this pollutant, not corrected[7] (kg of emitted pollutants/m^2 affected area/year)
B	...	number of buildings constructed (number of new buildings)
f	...	conversion factor (average affected area per building)
m	...	duration of construction activity (year)

The conversion factor (f) reflects the area of land affected by construction activities per building. For non-residential construction the affected area is assumed to be approximately equal to the building footprint area because this type of construction usually occurs in densely populated urban areas where space is very limited. The current average footprint area for non-residential buildings in Germany is about 800 m^2. The average footprint for non-residential buildings was derived from an analysis of a large number of construction projects in Germany. The used references for the estimation of average footage for the non-residential construction sector are given in Appendix 7.3.

To estimate the trends in the footprint development of non-residential buildings for the period between 1990 and 2013 the trend in development of utility space in Germany were assumed.

The duration of construction of a new non-residential building is assumed at 10 months. The dust-intensive processes usually occur in the first phases of the construction. Table 5 and Table 6 show the activity data and emission factors used.

7 soil moisture and silt content correction

Table 5: Activity data for emission calculation for non-residential buildings

Parameter	Available Statistics	
	Germany	Data quality
Number of new buildings constructed	Bauen und Wohnen, lange Reihe, Kap.3.1 (Destatis, 2014b)	sufficient; for new federal states data available from 1993 onwards
Usable area in m^2	Bauen und Wohnen, lange Reihe, Kap.3.1 (Destatis, 2014b)	sufficient; data available from 1993 onwards

Table 6: Emission factors for emission calculation for non-residential buildings

Pollutant	Emission factor value	Unit[8]	Reference
TSP	1.7037	kg/m²/year	WRAP 2006
PM10	0.5111	kg/m²/year	WRAP 2006
PM2.5	0.0511	kg/m²/year	WRAP 2006

4.3 Road construction

Road construction emissions are highly correlated with the amount of earth being moved. Almost all roadway construction involves extensive amounts of earth being moved and the use of heavy construction vehicles, causing emissions to be higher than for other construction activities (WRAP, 2006).

The emissions from road construction are calculated using the following formula:

$$EM = EF * M * f * m$$

where

EM … emission of the specified pollutant (tons)

EF … emission factor of this pollutant, not corrected (kg of emitted pollutants/m^2 affected area/year)

M … length of new road constructed (km)

f … conversion factor (m^2 area affected per m new road constructed (m^2/m))

m … duration of construction activity (year)

The EPA emissions factors are applicable only for new road construction. The conversion factor (f) reflects how many m^2 are affected by construction of 1 m roadway. For Germany we estimated a conversion factor of 36.4 m^2 affected area per meter new road construction. The conversion factor estimation is based on road structure (roadway width, lane and shoulder number). The detailed calculation steps for this conversion factor are shown in Table 14 in Appendix 7.4.

[8] All values have been converted from contractor to usual standard units

Table 7 and Table 8 show the used activity data and emission factors.

Table 7: Activity data for emission calculation for road construction

Parameter	Available Statistics	
	Germany	Data quality
km of new road constructed	Straßenbaubericht 1990-2006 Verkehrsinvestitionsbericht 2006-2013 BMVI (2014b)	sufficient; data available for highway and federal highway
Road structure data	Regelquerschnitt, Straßenaufbau (Autobahn Wiki, 2015)	sufficient

Table 8: Emission factors for emission calculation for road construction

Pollutant	Emission factor value	Unit[9]	Reference
TSP	3.766	kg/m²/year	WRAP 2006
PM10	1.130	kg/m²/year	WRAP 2006
PM2.5	0.113	kg/m²/year	WRAP 2006

The duration of the construction of a new road is assumed to be 12 months. The dust-intensive processes usually occur in the beginning of the construction (e.g. heavy construction, extensive earthmoving).

4.4 PM2.5/PM10 fraction

In general geological dust has a relatively low PM2.5 content in PM10. This is often also the case for other dust emissions with mechanical origin, whereas particles with thermal origin (e.g. an engine exhaust) usually almost entirely consist of PM2.5. We therefore expect the overall PM2.5 to PM10 ratio to be low, moreover since we exclude equipment exhaust emission.

According to (MRI, 2006) the overall PM2.5 fraction in PM10 of construction emissions varies between 5 and 15%, while (Muleski et al., 2005) measured 1–10% (av. 3%) for several specific sources, which is both roughly in line with other geological dust sources.

Both literature sources state that emission is largely geological dust. It can however not entirely be ruled out that there has been some influence of equipment exhaust emission on the overall measured PM2.5 fraction, since only the total emissions can be measured.

For construction as a whole we (conservatively) assume 10% PM2.5 in PM10. This value is considerably lower than what EPA previously recommended (20-30%) but likely more realistic. We estimate TSP emission to be 3.33 times the PM10 emission, based on a reported PM10 in TSP content of 30% (US EPA, 1999).

9 All values have been converted from contractor to usual standard units

4.5 Black Carbon (BC) Emissions

The contribution of the construction sector to total black carbon (BC) emissions in comparison to other categories is minor. The black carbon emissions are mainly caused by combustion processes. The dominant contributors are diesel vehicles, followed by wood combustion and wildfires.

Black carbon emissions from construction are mainly caused by mechanical processes or depend on black carbon content in soil or raw materials (Kupiainen & Klimont, 2004). Thus, the BC emissions from construction are negligible. The share of BC on PM2.5 for different source categories is given in Table 9.

Table 9: Share of black carbon on PM2.5 for different source categories (Battye, Boyer & Pace, 2002)

Category	Share of BC on PM2.5 in %
Fugitive dust (Construction)	0-0.5
Fugitive dust (Other)	0.6-1.3
Paved road dust	1.7-2.8
Unpaved road dust	1-1.9
On-road diesel vehicles	43-59
Industrial fuel combustion (Coal)	3.7-7.1
Industrial fuel combustion (Gas)	6.7-15
Industrial fuel combustion (Wood)	9.3-31
Open biomass burning (Wildfires)	7.2-12

4.6 Correction factors

As previously mentioned, the estimated emissions should be corrected according to regional soil moisture and silt content.

To account for the soil moisture level, the following equation is used (Thesing Kirstin B. et al.).

Moisture Level Corrected Emissions = Base Emissions * (24/PE)

PE … Thornthwaite Precipitation-Evaporation index

A PE index of 120 was estimated for Germany.

To account for the silt content, the following equation is used:

Silt Content Corrected Emissions = Base Emissions * (s/9 in %)

An average silt content of 20% was estimated for Germany.

To correct the estimated emissions in Germany, the basic emissions should be multiplied by factor of 0.2 for moisture correction and by factor of 2.22 for silt content correction.

The corrected emissions factors are shown in Table 10. The estimation of correction factors is described in chapter 4.6.2.

Table 10: Soil moisture and silt content corrected emission factors for Germany

Pollutant	Construction type				Unit	Reference
	Single-/Two-family house	Apart-ments	Non-residen-tial	Road con-struction		
TSP	0.1274	0.4379	0.7564	1.6721	kg/m²/year	WRAP 2006
PM10	0.0382	0.1314	0.2269	0.5016	kg/m²/year	WRAP 2006
PM2.5	0.0038	0.0131	0.0227	0.0502	kg/m²/year	WRAP 2006

4.6.1 Correction for soil moisture content

The EPA Tier 1 method offers the possibility to correct for climatic conditions influencing the soil moisture content, as soil moisture content has a profound influence on geological dust emissions. As an indicator of the soil moisture content the Thornthwaite precipitation-evaporation (PE) index is used, which is calculated based on the monthly precipitation P_i and the mean temperature T_i according to:

$$\text{PE index} = 3.16 \sum_{i=0}^{12} \left(\frac{P_i}{1.8\,T_i+22}\right)^{\frac{10}{9}}$$

This method of classifying climatic conditions has been developed for the eastern part of the US with only limited applicability for other regions in the world, although it is widely used for other regions. For use for Germany an average PE value of 120 is selected, which corresponds to the average values found for the North/Central-Eastern part of the US. The average PE value for California/Las Vegas is 24, which leads to a correction factor of 0.2. It should be noted that a value of 120 is quite far from the reference value of 24, which implies that a profound degree of correction (0.2) takes place as a result of the relatively high soil moisture content in Germany compared to the arid regions of the US. It is at this stage unfortunately not possible to verify if this degree of correction still produces realistic results. Ideally this should be backed by measurements.

4.6.2 Correction for silt content

To be able to apply the EPA Tier 1 methodology to Germany a representative estimate of the average soil silt content at the construction site is required. When examining the undisturbed natural soils occurring in Germany it appears that because of the domination of the loamy brown earth the silt content is quite high (weighted average for Germany is 38%). The reported soil silt content is an average of the first 1.2 meters of the natural undisturbed soil. Our interest is primarily in the first few centimeters, as this layer will have the highest influence on resuspension. This top layer will be richer in organic material and hence have somewhat lower silt content than the deeper layers. In addition, and this is even more important, at actual construction sites a natural undisturbed soil is usually not present.

When preparing a certain area to be built upon, the natural soil is removed to a certain depth and a layer of sand is poured that will provide a stable basis for the construction. Loam and clay soils or soils with a high organic content are usually not stable enough to build directly upon. This implies that at least for the area on which the building will actually be placed the top soil will be replaced entirely by sand at an early stage of the construction project. Also areas that will eventually be paved in some way require a layer of sand as a basis. Sand has a silt content of only about 10% and some grades of construction sands even as low as 2%. Another reason for lower silt content is that in cities the soil is usually anthropogenic to begin with, with most anthropogenic soil being mostly sandy.

Those sections of the area affected by a construction project that keep their natural soil layer on top but nevertheless remain bare throughout the duration of the construction project may have higher silt content than that of sand. Also temporarily unpaved roads used for hauling of materials may extent over areas with an undisturbed natural soil. But this will never be occurring at the whole affected area.

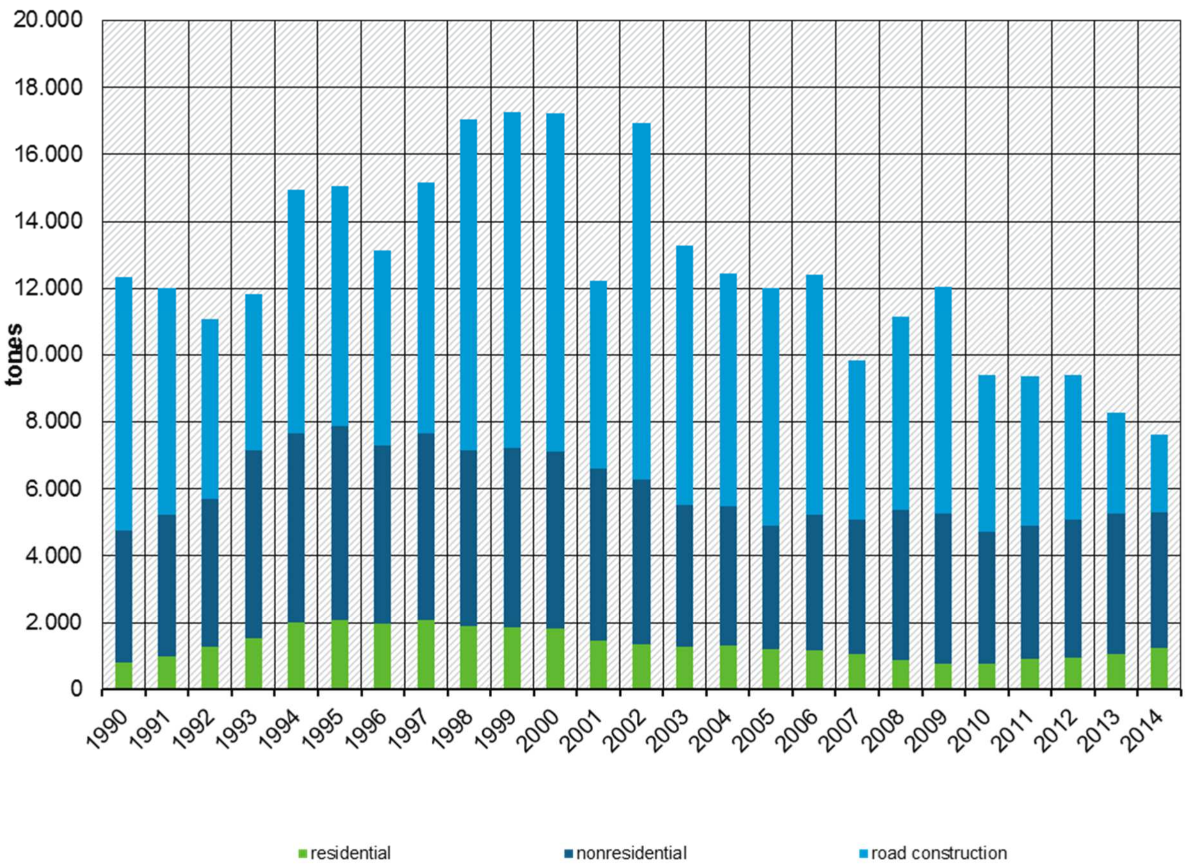
Based on the above we cannot regard the average silt content of the first meter of the undisturbed natural soil (38% according to (BGR, 2007)) as representative for construction sites in Germany. Nor can we assume the silt content of sand (10%) as representative for the entire affected area throughout the duration of the project. Thus an average silt content of 20% (10-30%) has been assumed to be representative for all construction sites in Germany. This value could be further validated and/or differentiated in the future. The average silt content for California/Las Vegas is 9%, which leads to a correction factor of 2.22.

5 Results

5.1 Emissions from construction activities in Germany

Figure 1 and Figure 2 show the results of the calculation of PM10 emissions from construction for Germany. The estimated emissions for PM2.5 and TSP are shown in Annex 7.5. The total PM10 emission from construction in Germany in 2014 is around 7.6 kt. The highest contribution is made by the construction of non-residential buildings (4.1 kt). Road construction contributes for around 2.3 kt and the construction of various types of housing about 1.2 kt PM emissions. The share of PM10 emissions from construction to the total PM10 in Germany is around 3.6%, whereas that of PM2.5 is far lower (about 1%).

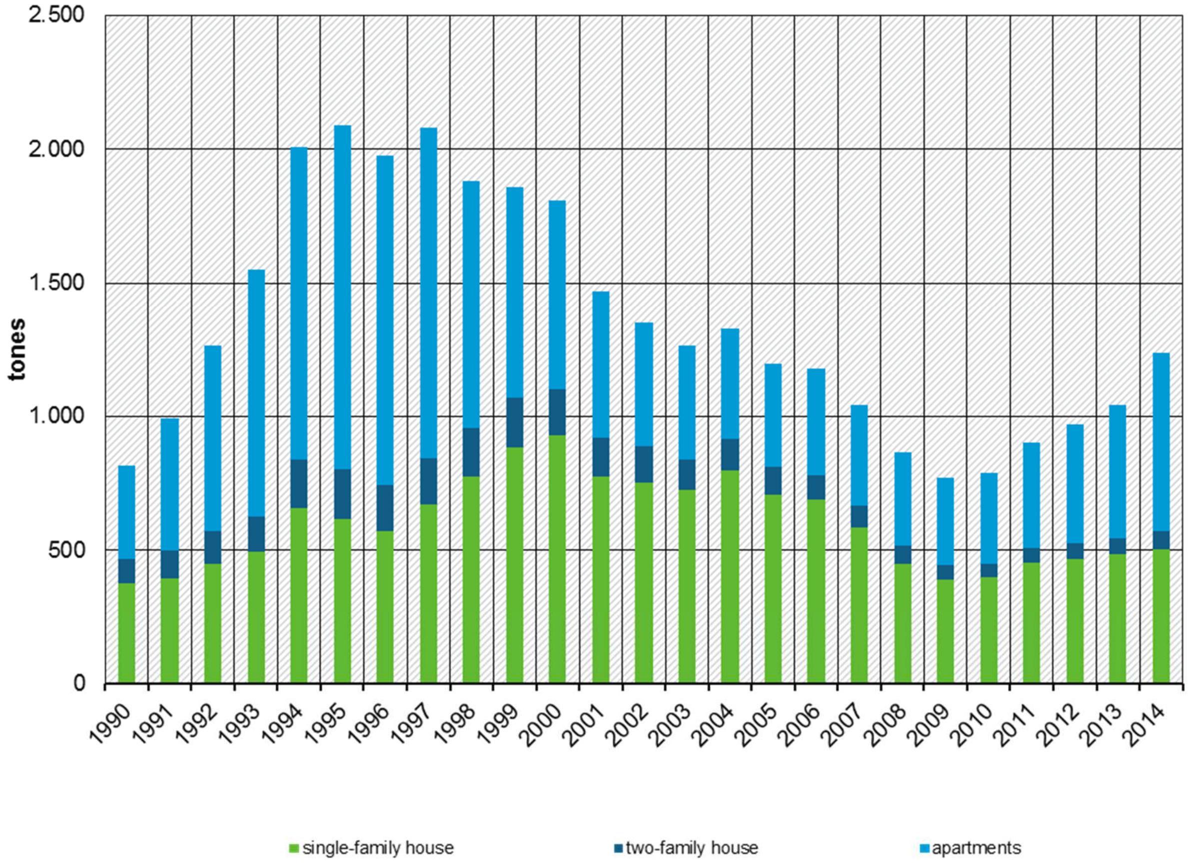
Figure 1: PM10 emissions for residential, non-residential buildings and road construction in Germany (moisture/silt content corrected), data for 1990 to 1993 only for West Germany ('old federal states') [10]



As Figure 1 shows, the emissions begin to decline after 2002. The higher emissions between 1993 and 2000 can be explained by a construction boom after reunification in particular regarding residential buildings and road construction. The emission trends correlate with the development of the activity data, see Figure 3 and Figure 4.

[10] The calculations between 1990 and 1993 from building construction consider the construction activities only for old federal states.

Figure 2: PM10 emissions from residential construction in Germany (moisture/silt content corrected), data for 1990 to 1993 only for West Germany ('old federal states') [11]



[11] The calculations between 1990 and 1993 from building construction consider the construction activities only for old federal states.

Figure 3: Number of completed buildings in Germany

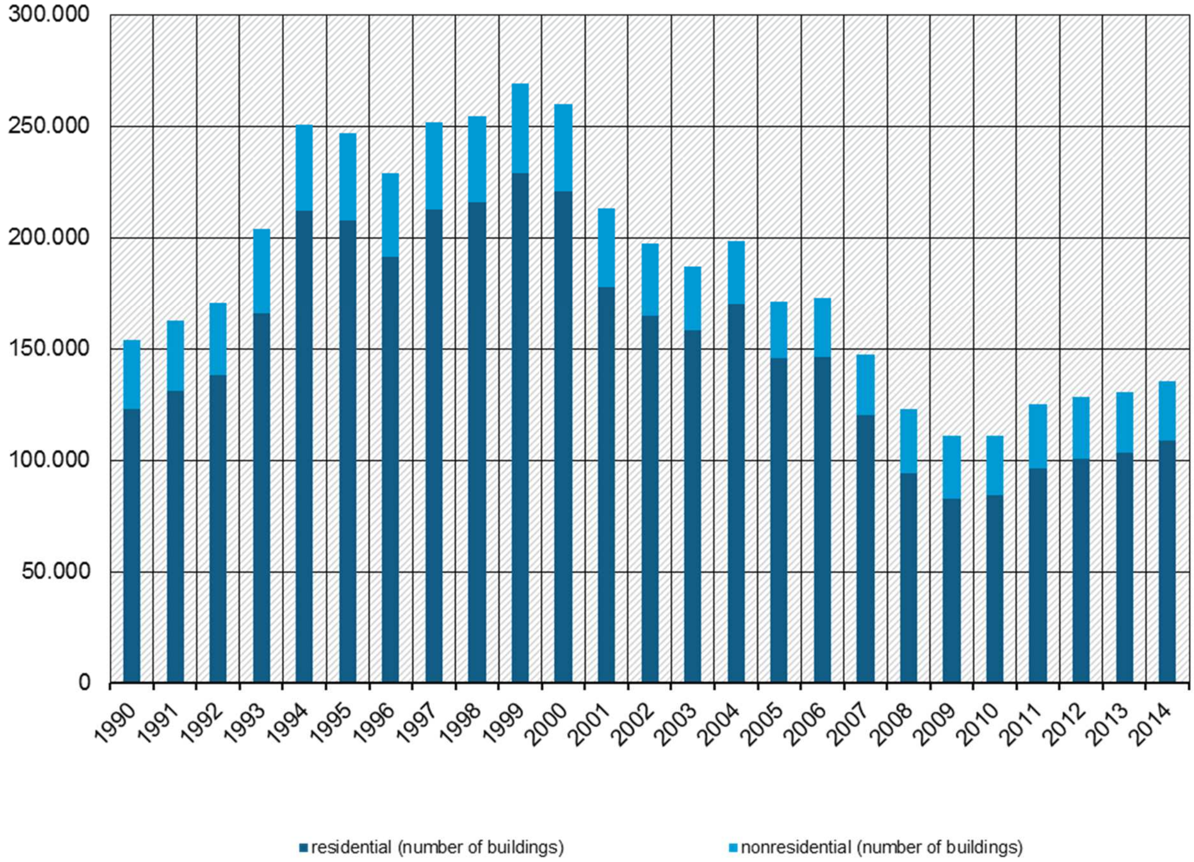


Figure 4: Activity data for road construction in Germany

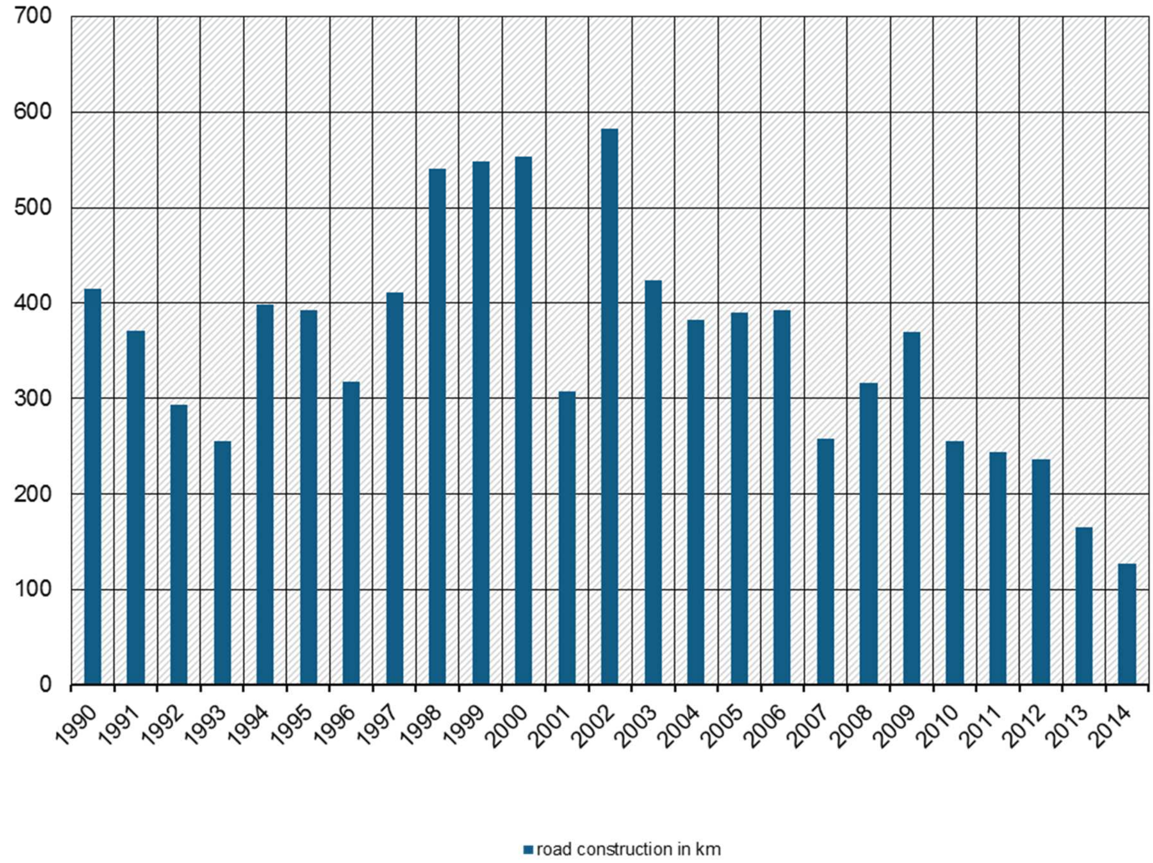


Table 11 shows the officially reported emissions from construction and demolition activities for several European countries. For Germany the results based on two different calculation methodologies are also shown (see section 5.2). The current UBA emissions do not include the emissions from road construction. It is noticeable, that the UK emissions are quite low. The UK emission calculation is based on EPA methodology (see Table 1). The used PM10 emission factor of 0.0072 kg/m^2/year is significantly lower than the emission factor of 0.0861 tons/m^2/year for residential houses in Germany. It is very difficult to compare these factors. There is not enough detailed information about UK emission factors available, e.g. information about silt/moisture correction or information, which construction activities were considered.

Table 11: Officially reported PM10 emissions from construction and demolition for several EU countries in kt

Country	1995	2005	2013
Austria	1.0	1.0	1.3
France	33.9	32.6	25.4
Germany (this study calculation)	**15.1**	**12**	**8.3**
Germany (current UBA calculation)	**4.7**	**3.0**	**3.2**
Norway	0.8	1.1	1.2
Poland	0.5	1.0	1.2
Sweden	0.4	0.7	0.6
United Kingdom	1.0	1.0	0.5

5.2 Discussion of the results

Above all, the newly estimated PM10 construction emissions, with a total amounting to 7.6 kt, is considerable compared to other known sources of PM10. For the year 2014 the estimated emission puts the contribution by construction in the same order of magnitude as for instance the emission of agricultural activities excluding emission from animals (about 18 kt) or the emission by the use of products (tobacco and fireworks) and food barbequing together (about 14 kt). Because particulate matter from construction is mainly coarse (PM2.5-10), the contribution to PM2.5 is much lower and far less significant (1.2 kt).

Previously the German emission from construction was estimated based on the old Guidebook Tier 1 method, at a little over 3 kt, which is confirmed by this study's attempt to extrapolate the current estimate for the Netherlands to the German situation (3–5 kt for Germany, see Appendix 7.2). Certainly of influence to the difference is the very low contribution of soil dust in the Dutch methodology, whereas this is the largest component of the US EPA Tier 1 method (and likely rightfully so, at least for the arid regions of the US). In the Dutch methodology the largest contribution (although still modest in absolute figures) comes from building and finishing activities rather than soil dust. Extrapolated to Germany these building and finishing activities would amount to 2–4 kt PM10 according to the Dutch methodology (roughly a quarter of the new estimate for the total construction emission). In the US EPA Tier 1 methodology the contribution of these building and finishing activities is not singled out or separately addressed anywhere. This may suggest that according to EPA the contribution of building and finishing activities may always be considered negligible compared to the soil dust contribution. But it remains uncertain whether this is still the case when soil dust emission has to be corrected downwards to the degree as has been done in this study.

Although the EPA uses the Tier 1 method for all regions of the US (including wet temperate regions), it could be argued that its applicability is stretched when correcting for specific German conditions, and that it does not produce reliable results anymore. Compared to the arid conditions under which the PM10 emissions were originally measured in the US, the overall correction factor to adapt the measurement results to specific German conditions is only 0.44. This very moderate degree of correction may seem counterintuitive but there is no methodological reason for any further downwards correction. The authors of this report nevertheless reckon with a possible overestimation of the soil dust emissions, thus interpreting the chosen approach as conservative.

All four US EPA Tier 1 emission factors are based on the extent of the affected area by a construction project as activity parameter. Since affected area is not available from any statistical source, surrogate statistics and conversion factors must be used to estimate the affected area. For Germany we estimate that the affected area is roughly 1.5 times the footprint area of the building. EPA uses a much higher conversion factor for the US, suggesting that in Germany the average construction site has a much more compact layout.

Another uncertain element in the US EPA Tier 1 method is the assumed total duration of the construction. During this period the real world emissions will be highly fluctuating, for instance depending on which activity is taking place and the soil moisture content at that moment. The EPA emission factors are averaged over the total duration and thus linearly dependent on it. It is however not described exactly how EPA defines the duration of the construction and this could introduce some additional uncertainty.

In spite of all of the above made considerations the authors of this study still believe that the US EPA Tier 1 method is a considerable improvement over the old Guidebook Tier 1 methodology, simply by the fact that the Dutch methodology largely seems to miss the main contribution, which is soil dust.

5.3 Uncertainties

In estimating the overall uncertainty of the results we must consider all of the above, as well as the fact that even under optimal conditions the US EPA Tier 1 method is already highly uncertain.

There is a methodological uncertainty in the basic emission factors and in the way of correction, in addition to the representativeness of the conversion factors for the affected area and the construction duration. Then there is a possibility that certain contributions such as by finishing may be largely overlooked (although there are no direct indications for this). At this stage however it is not possible to calculate how these factors propagate in the overall uncertainty. Only a more or less subjective evaluation of all factors contributing to the overall uncertainty can be made. In addition a cap can be put on the maximal contribution of construction activities by analyzing the background soil dust content of ambient PM10 (see section 5.4). Normally in this type of analysis uncertainties in the individual components tend to average out in the final result, provided that individual uncertainties are independent of each other. An example for this is the assumption for Germany that the affected area per building is so much lower than in the US partly offsets possible overestimation by the corrected emission factors

When we define a 95% confidence interval as a lower limit we might consider a severe overestimation of the soil dust emission with only building and finishing emissions remaining. As a lower boundary of the building/finishing contribution we may consider a quarter of the emissions calculated with the Dutch methodology for Germany, which would be around 1 kt. For considering an upper limit we may assume that emissions can never be larger than a certain fraction of the total emission of geological dust in Germany.

The total emission of soil dust is indicatively estimated to be 50 kt (see section 5.4) with resuspension by road transport identified as one of the major contributors. We will assume 25 kt for now as upper limit (half of the total soil dust emission), leading to an overall uncertainty range of 1 to 25 kt with 12.1 kt as current best estimate for 2013.

5.4 Comparison of the results with the total contribution of mineral dust as derived from PM10 elemental composition data

Besides construction activities, soil dust (or mineral dust) smaller than 10 µm may originate from a variety of different natural or anthropogenic sources, such as wind erosion of bare soils, agricultural land management, driving on unpaved roads and resuspension of road dust. Because mineral dust likely comprises the biggest part of construction emissions it could be argued that the contribution of construction emissions to ambient PM10 levels will almost certainly not exceed the total contribution of mineral dust.

The total contribution of mineral dust to ambient PM10 levels can be estimated on the basis of (tracer) elements that originate from mineral dust, for instance silicon and aluminium. In (Denier van der Gon et al., 2015) elemental composition data of ambient PM10 and PM2.5 have been collected from 55 reviewed European studies, including five for Germany. Based on typical compositions of soil top layers, apparent contributions of mineral dust were estimated by (Denier van der Gon et al., 2015). For Germany contributions to PM10 background concentrations during 2000 to 2005 were found to range from 8 to 16% (av. 13%). At a street location mineral dust contributions was much higher (e.g. 30%), suggesting that resuspension due to road traffic is one of the main contributors.

At that time total emission of primary PM10 was about 260 kt in Germany, possibly causing roughly 60% of the ambient PM10 levels in Germany (the remaining 40% being caused by foreign contributions and secondary PM). One might reason that if 260 kt causes 60% then 13% may be caused by 50 kt. 50 kt would then be the total emission of mineral dust in Germany.

Besides construction, resuspension by road transport, dust emissions from agricultural activities and windblown dust from bare soils are known to be potentially large mineral dust sources. The estimated construction emissions of 25 kt for that specific period may seem considerable in this respect but would not be in contradiction to an indicative total mineral dust emission of 50 kt.

6 Literature

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7 Appendix

7.1 Summary of the Dutch methodology to estimate emissions from the construction industry

In the Dutch methodology four types of companies are distinguished:

- Civil engineering (ca. 4000 companies, 66000 employees)
- Construction of residential housing and utility dwellings (ca. 20000 companies, 150000 employees)
- Demolition (ca. 600 companies, 3000 employees)
- Finishing contractors (ca. 16000 companies, 60000 employees)

A step-by-step calculation yields the following:

a) Civil engineering

Dust resuspension: EF = 0.45 kg/VKT, based on Cowherd et al. 1990 (Dutch silt content, precipitation, vehicle characteristics); VKT are estimated based on various construction activity data.

Emission = 196 tonnes

Windblown dust from earth moving: EF = 3.9 kg/Ha, based on Cowherd et al. 1990 (Dutch silt content); the area is estimated from various construction activity data.

Emission = 13.6 tonnes

b) Construction of residential housing and utility dwellings

Emission from specific activities

Emission estimated based on:

- Number of employees in 15 different métiers/professions within the sector
- Number of working hours of main activity
- Dust exposure during main activity
- Assumed dispersion parameters/flux windows

Emission = 568 tonnes

Emission from a-specific activities

The emission is assumed to be mainly dust resuspension from construction-related transport on unpaved roads. It is based on the estimates of total volume/tonnage building materials to be transported to build the annual number of houses/utilities.

Emission = 30 tonnes

c) Demolition

Two types of demolition activities are being distinguished: indoors (e.g. before renovation) and outdoors (destruction). The emission is estimated by an exposure-based method as well as a method based on emission factors (in parallel). The exposure-based method is based on observed and allowed indoor concentrations, ventilation ratios, average duration of indoor demolishing and volume of renovated houses/utilities; there are no data available to apply the exposure-based method to outdoor demolishing (emission assumed to be identical to indoor).

Exposure-based method: Total = 9 to 34 t.

The method based on emission factors is based on factors for mobile crushing equipment and the estimated amount of construction debris produced.

Emission factor-based method = 25.7 t.

Average of both methods (best estimate) is 20 t.

d) Finishing contractors

Emission estimated based on:

- Number of employees in 6 different métiers/professions within the sector
- Number of working hours of main activity
- Dust exposure during main activity
- Assumed dispersion parameters/flux windows

Emission = 234 tonnes

Total PM10 emissions from the construction industry in the Netherlands in 1999: 1062 t

7.2 Extrapolation of Dutch method to Germany

An extrapolation of the Dutch PM10 emissions by construction activities to the German situation has been made. The original reference year of the Dutch methodology is 1997, which we have extrapolated to Germany in 2013.

In the Dutch methodology there are the following contributions (see summary of the Dutch methodology):

- Civil engineering, dust resuspension: 196 ton
- Civil engineering, windblown dust: 14 ton
- Construction of buildings, building activities (e.g. concrete mixing, sanding, grinding, welding, masonry etc.): 568 ton
- Construction of buildings, dust resuspension: 30 ton
- Demolition: 20 ton
- Finishing activities: 234 ton

From Eurostat the total number of active workers in 2013 for both countries, for each of these activities, is known from the Eurostat Structural Business Statistics. These data are normalised to the total number of workers in the whole construction sector according to the Eurostat National Accounts (which give a more complete picture of the actual numbers and are also available for the Netherlands in 1997). The results for the Netherlands in 1997 are compared to the ones for Germany in 2013 in the graph below.

Based on the number of active persons in the subsectors our extrapolation results in a total estimated PM10 emission for Germany in 2013 of 3.7 kt (see table below).

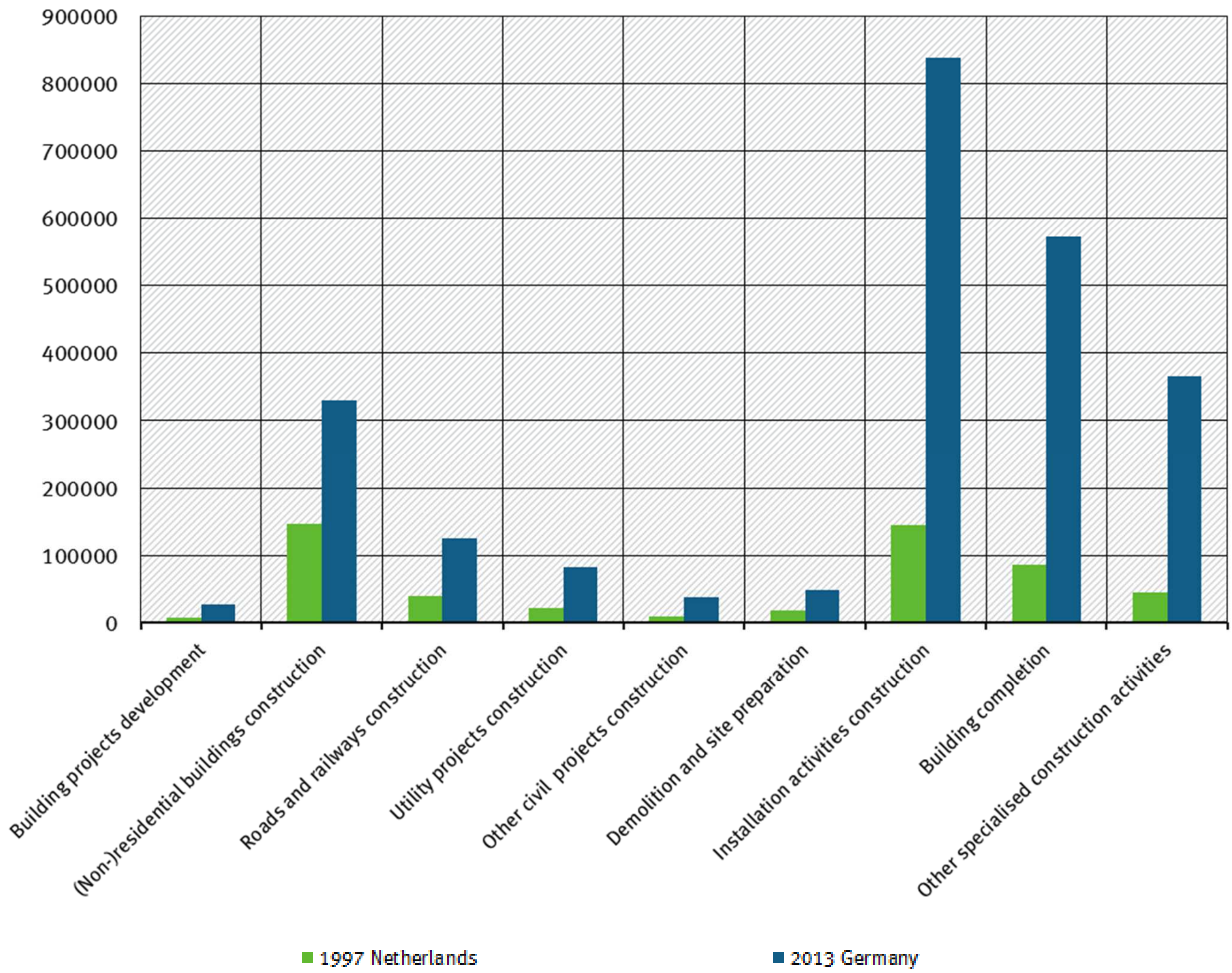
Table 12: PM10 emissions for Germany in 2013 based on Dutch methodology

Sector/source	1997 Netherlands	2013 Germany
Civil engineering		
Dust resuspension	196	680
Windblown dust affected areas	13.6	47
Construction of residential housing and utility dwellings		
Emission from specific activities	568	1274
Dust resuspension	30	67
Demolition	20	52
Finishing	234	1560
Total above	1,062	**3,681**
Total based on total number of workers in construction	1,062	**4,966**

We use Eurostat data because we aim to maximize the chances for a consistent definition of the activities between the two countries. Nevertheless, some inconsistencies are suggested when comparing the numbers for "Construction of residential and non-residential buildings" (which is a proxy for the 568 ton) for which Germany appears only twice as big as the Netherlands, whereas we expect it to be about five times as big. Other categories seem much higher than a factor of 5 (e.g. finishing).

To avoid having these inconsistencies influence the result too much, a second extrapolation is made based on the construction sector as a whole (averaging out different definitions of subactivities). This leads to about 5 kt PM10 for Germany in 2013 (see table above, bottom row).

Figure 5: Number of workers in the construction sector



7.3 References for construction projects in Germany

The average footprint for different buildings types in Germany was derived from various construction project data. References are given in the table below.

Table 13: Assumed average footprint for residential buildings in Germany

Residential buildings	Assumed footprint in m²	Range in m²	References for residential buildings
single-family house	150	70-210	Bauratgeber-HausXXL, http://www.haus-xxl.de/
two-family house	250	80-330	http://www.praktikhaus.de/
apartments	450	230-1100	http://www.ott-haus.de/haeuser.html
			http://www.hartlhaus.de/
			www.immonet.de
			www.immobilienscout.de
			http://www.hauscompagnie.de
			https://www.variohaus.de/
Non-residential buildings	**Assumed footprint in m²**	**Range in m²**	**References for non-residential buildings**
	800	560-4500	http://www.mokrani.de/index.php?article_id=4
			http://www.benthaus.com
			http://www.berlin-spart-energie.de/energiesparprojekte/projekt/objectdetails/16.html
			http://www.ib-baunach.de/Referenzen.2.0.html?&no_cache=1

7.4 Estimation of conversion factors for road construction

Table 14: Estimation of conversion factors for road construction[12]

Road structure data	Municipal roads	State roads	Federal highway	Highway with 4 side-strip	Highway with 6 side-strip
Lane width in m	2.75	3	3.5	3.5	3.5
Number of Lanes in one direction	2	2	2	4	6
Shoulder width in m	1	1.5	1.5	1.5	1.5
Side-strip	0	0.25	0.25	0.5	0.5
Number of shoulders in one direction	1	1	1	1	1
Roadway width for two directions in m	13	15.3	17.3	31.5	45.5
Area affected beyond road width in m[13]	5	5	5	5	5
Width affected in m					
Area m² affected per m of new roadway[14]	**18.000**	**20.250**	**22.250**	**36.500**	**50.500**

12 Calculation steps for conversion factor are based on EPA methodology WRAP 2006; The data about structure of different road types in Germany is taken from: Autobahn (2015)

13 Derived from EPA default factors; EPA assumes 25 feet (7.62 m) for affected area.

14 Average conversion factor for federal roads and highways is around 36.4 m² affected area/m new road constructed

7.5 Emissions

Table 15: PM10 emissions from construction in Germany in tons (moisture/silt content corrected)

Year	Residential	Non-residential	Road construction	Total
1990	817.0	3937.2	7588.8	**12,343**
1991	993.9	4242.8	6776.9	**12,014**
1992	1264.3	4441.1	5367.0	**11,072**
1993	1549.1	5616.7	4677.6	**11,843**
1994	2010.1	5655.8	7290.7	**14,957**
1995	2091.5	5799.4	7177.4	**15,068**
1996	1978.2	5330.5	5809.6	**13,118**
1997	2083.0	5563.9	7519.3	**15,166**
1998	1881.4	5264.6	9892.9	**17,039**
1999	1857.4	5380.4	10028.2	**17,266**
2000	1807.6	5308.5	10112.3	**17,228**
2001	1470.3	5148.0	5623.0	**12,241**
2002	1349.4	4940.0	10662.7	**16,952**
2003	1263.4	4254.7	7760.7	**13,279**
2004	1328.2	4142.3	6983.5	**12,454**
2005	1199.2	3686.8	7129.8	**12,016**
2006	1177.6	4049.5	7166.4	**12,393**
2007	1044.9	4053.2	4719.7	**9,818**
2008	866.6	4496.5	5776.6	**11,140**
2009	770.2	4496.5	6762.3	**12,029**
2010	790.0	3934.4	4672.2	**9,397**
2011	902.5	4015.5	4450.9	**9,369**
2012	970.2	4110.7	4326.5	**9,407**
2013	1045.1	4205.4	3030.0	**8,281**
2014	1238.8	4062.4	2322.4	**7,624**

Table 16: PM2.5 emissions from construction in Germany in tons (moisture/silt content corrected)

Year	Residential	Non-residential	Road construction	Total
1990	81.7	393.7	758.9	**1,234**
1991	99.4	424.3	677.7	**1,201**
1992	126.4	444.1	536.7	**1,107**
1993	154.9	561.7	467.8	**1,184**
1994	201.0	565.6	729.1	**1,496**
1995	209.1	579.9	717.7	**1,507**
1996	197.8	533.0	581.0	**1,312**
1997	208.3	556.4	751.9	**1,517**
1998	188.1	526.5	989.3	**1,704**
1999	185.7	538.0	1002.8	**1,727**
2000	180.8	530.8	1011.2	**1,723**
2001	147.0	514.8	562.3	**1,224**
2002	134.9	494.0	1066.3	**1,695**
2003	126.3	425.5	776.1	**1,328**
2004	132.8	414.2	698.4	**1,245**
2005	119.9	368.7	713.0	**1,202**
2006	117.8	404.9	716.6	**1,239**
2007	104.5	405.3	472.0	**982**
2008	86.7	449.6	577.7	**1,114**
2009	77.0	449.6	676.2	**1,203**
2010	79.0	393.4	467.2	**940**
2011	90.2	401.5	445.1	**937**
2012	97.0	411.1	432.7	**941**
2013	104.5	420.5	303.0	**828**
2014	123.9	406.2	232.2	**762**

Table 17: TSP emissions from construction in Germany in tons (moisture/silt content corrected)

Year	Residential	Non-residential	Road construction	Total
1990	2723.3	13124.0	25296.1	**41,143**
1991	3313.1	14142.8	22589.7	**40,046**
1992	4214.2	14803.8	17890.1	**36,908**
1993	5163.7	18722.3	15592.1	**39,478**
1994	6700.3	18852.7	24302.5	**49,856**
1995	6971.7	19331.4	23924.6	**50,228**
1996	6594.1	17768.3	19365.2	**43,728**
1997	6943.2	18546.4	25064.4	**50,554**
1998	6271.4	17548.8	32976.3	**56,797**
1999	6191.2	17934.6	33427.4	**57,553**
2000	6025.3	17695.0	33707.8	**57,428**
2001	4901.0	17160.1	18743.5	**40,805**
2002	4498.1	16466.6	35542.5	**56,507**
2003	4211.5	14182.5	25869.0	**44,263**
2004	4427.4	13807.6	23278.5	**41,514**
2005	3997.4	12289.5	23766.1	**40,053**
2006	3925.2	13498.2	23888.0	**41,311**
2007	3483.1	13510.6	15732.3	**32,726**
2008	2888.8	14988.3	19255.5	**37,133**
2009	2567.2	14988.3	22540.9	**40,096**
2010	2633.4	13114.5	15573.8	**31,322**
2011	3008.3	13385.0	14836.3	**31,230**
2012	3234.1	13702.3	14421.8	**31,358**
2013	3483.5	14018.0	10100.1	**27,602**
2014	4129.4	13541.2	7741.2	**25,412**

7.6 Literature review

To identify an applicable methodology for estimating fugitive PM emission from construction activities for Germany and Europe the following literature sources were examined.

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