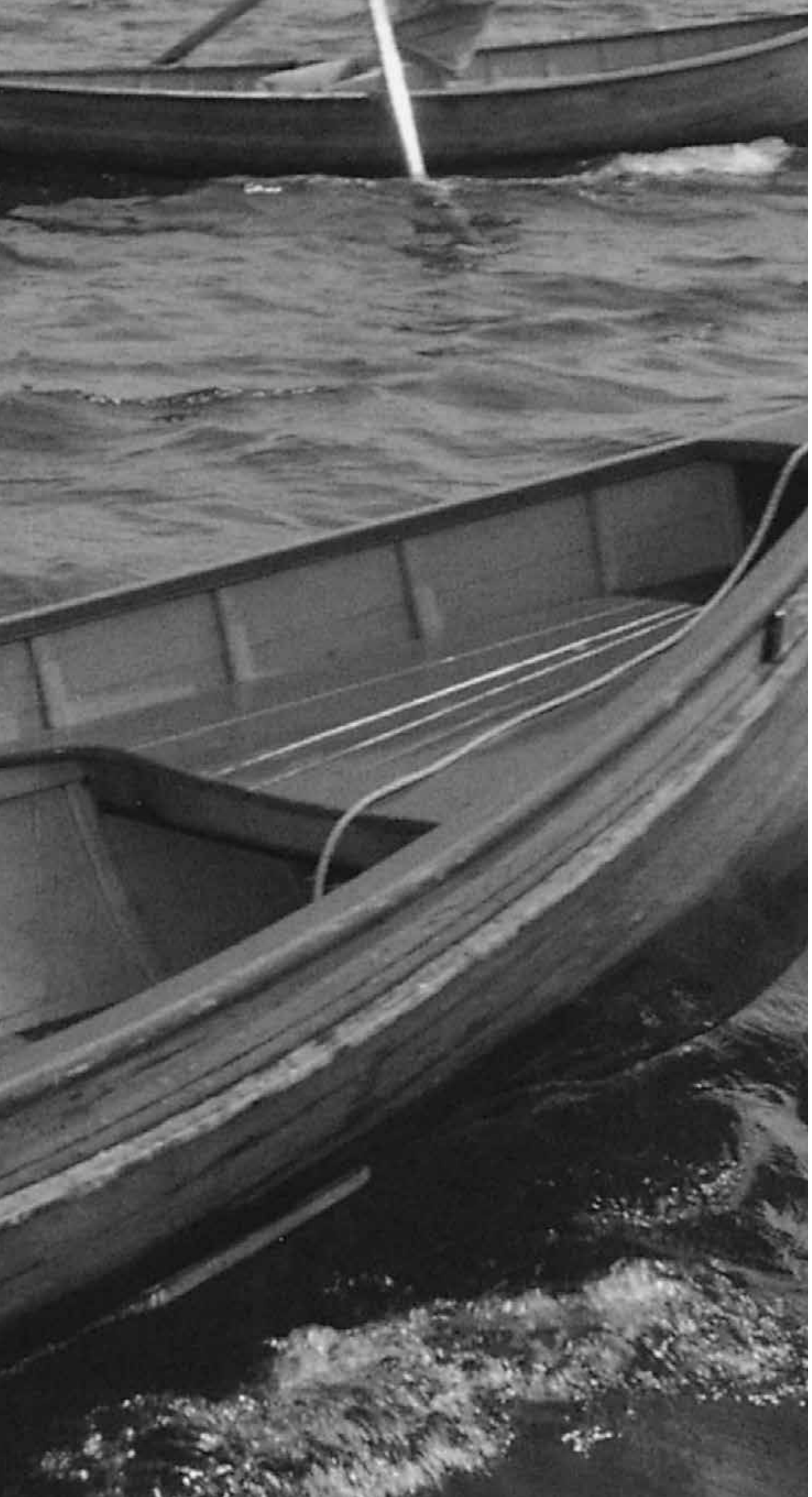
هيئة البيئة - أبوظبي
Environment Agency - ABU DHABI

Abu Dhabi Air Emissions Inventory

2018

Photography: ADNOC, Emirates Global Aluminium, Xavier Eichaker, John Davis, Hanne & Jens Eriksens, and EAD.



عام زايد

YEAR OF ZAYED

''إن حماية البيئة يجب ألا تكون وألا ينظر إليها
كقضية خاصة بالحكومة والسلطات الرسمية فقط،
بل هي مسألة تهمنا جميعا.

إنها مسؤولية الجميع ومسؤولية كل فرد في
مجتمعنا، مواطنين ومقيمين.''

الشيخ زايد بن سلطان آل نهيان طيّب اللّه ثراه

"We stress that conservation of the environment is not, and must not be seen as, a matter only for Government or officials. It is something that concerns us all.

This is a responsibility for all, every member of our society, both nationals and other residents."

Sheikh Zayed bin Sultan Al Nahyan

The Abu Dhabi Air Emissions Inventory report, produced by the Environment Agency – Abu Dhabi in the Year of Zayed, represents a milestone achievement in preserving and protecting our natural resources, building on our founding father's legacy of environmental conservation.

Preface

Good air quality in the Emirate of Abu Dhabi is a priority for our leadership, and a framework to improve air quality is included within the **Abu Dhabi Plan.** Environment Agency – Abu Dhabi (EAD) has developed a comprehensive air quality management plan to monitor the emirate's air quality and implement the most appropriate policies, regulations and incentives, collaborating with a wide range of public and private stakeholders.

This report gives a description of the work and results obtained in the update of the emission inventory for criteria pollutants carried out in the period 2015-2018. The overall aim of the project was to develop an emission inventory for criteria pollutants in Abu Dhabi Emirate, in order to update the previous inventory for the year 2009. The work has been performed in close cooperation between the Environment Agency - Abu Dhabi (EAD); local and federal government entities; and most importantly, the cornerstone of this project, our public and private stakeholders, who shared their sector-specific knowledge and information that helped build this emission inventory.

This report summarises the methods selected for estimating anthropogenic emissions, the input data and the resulting emission inventory for criteria pollutants for the base year 2015. The pollutants included in the emission inventory are nitrogen oxides (NO_X), sulphur dioxide (SO_2), particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOC). The report is structured according to relevant sectors, with specific chapters dedicated to the method and emissions for the sector.

Acknowledgements

This project is part of EAD's comprehensive programme for Air Quality Management in Abu Dhabi Emirate. A multidisciplinary team was involved in developing the Abu Dhabi Air Emissions Inventory – 2018, which could not have been produced without the commitment, data and review from the experts of many different sectors.

EAD would like to thank all the individuals and organisations for their contributions to the Abu Dhabi Air Emissions Inventory Report - 2018.

Environment Agency – Abu Dhabi (EAD)
H.E. Razan Khalifa Al Mubarak, Secretary General
Sheikha Ahmed Al Hosani, Executive Director, Environmental Quality Sector

EAD Project Management Team:
Ruqaya Mohamed
Oriol Teixido
Mariam Al Memari

EAD Project Technical Team:
Oriol Teixido
Rashed Al Kaabi
Hussein Hamed

Acknowledgements

Stakeholders Technical Team:

Entisar Al Khatheeri, ADNOC
Ahmed Al Shaibani, DOT
David Robinson, DOT
Andrew Clarke, DOT
Dr. Mansour Malik, DOT
Sanjeev Sharma, Abu Dhabi Ports
Ahmed Helal, ADWEA
Sameh Raafat, SCAD
Nabeel Al Awlaqi, DED/IDB
Khawaja Hassan, DED/IDB
Mohammad Al Jawi, EGA
Eiman Al Obaidli, EGA
Abdelmoneim Tawfik, ESI

EAD Project Technical Support Team:

Abdul Salam Al Hashmi
Ibrahim Al Ali
Husameddin Al Hag Ali
Maha Al Yafei
Lina Abdalla
Nesma Othman
Ahmed Al Ali
Nasser Al Nuaimi
Mohammad Alam
Mouza Ismail Al Zaabi
Mohammed Riyaz Azam
Ahlam A. Salem
Robert A. Zerbonia
Mark Turner
Zied Bousserouel
Ala'a Rezeq
Saif Dulaimi
Ahmed Rady
Samer Akl
Richard Perry
Monir Bou Ghanem
Sheshank Aggarwal
Prashanth Veldhi
Habiba Bamatraf
Anil Kumar
Sai Ravi Tubati
Anuja Vijayan
Tariq Al Kharusi
Hamad Al Ansari
Yasser Othman
Laila Al Hassan
Khansa Al Blouki
Ebtesam Al Harthi
Amani Issa
Mousatafa Nemr

NILU Project Team:

Susana López-Aparicio
Rebecca J. Thorne
Alena Bartonova
Henrik Grythe
Dam Thanh Vo
Claudia Hak
Dag Tønnesen

Government Entities

Ministry of Climate Change and Environment (MOCCAE)
Abu Dhabi Airports Company (ADAC)
Abu Dhabi Food Control Authority (ADFCA)
Abu Dhabi Police
Abu Dhabi Ports Company
Abu Dhabi Water and Electricity Authority (ADWEA)
Department of Transport (DOT)
Department of Urban Planning and Municipalities (DPM)
Industrial Development Bureau (IDB/DED)
Statistics Centre - Abu Dhabi (SCAD)

Semi-Government/Private Sector

Abu Dhabi National Oil Company (ADNOC)
Emirates Global Aluminium (EGA)
Emirates Steel
Admak General Contracting Company WLL
Al Jaber Asphalt Factory
Copri Construction Enterprises Establishment
Factory of Western Bainoona for Asphalt Manufacturing LLC
Ghantoot Transport & Contracting Establishment
Tarmac Abu Dhabi Limited Co - Al Mafraq branch
Tarmac Abu Dhabi Limited Co - Al Ain branch
Al Ain Cement Factory
Arabian Cement Industry LLC
National Cement Factory LLC
Teba Cement Factory LLC
Al Ain Ceramic Factory
Al Falah Readymix LLC (Branch 3)
Al Falah Readymix LLC (Branch 4)
Bin Fadel Al Mazrouei Ready Mix Est.

Cement Enterprises & Ready Mix (CEMIX) LLC
CEMEX Super Mix LLC
City Block Cement Products Factory
Eugene International LLC
Excellent Pipes Company LLC
Quick Mix Beton LLC
Quick Mix Beton LLC (Branch 1)
Quick Mix Beton LLC (Branch 2)
Redco Bin Juma Ready Mix Factory LLC
Sodamco Emirates Factory for Building Material LLC
Square General Precast LLC
Synaxis Readymix LLC
Technical Ready Mix Concrete Co
Techno Cast Precast LLC
Tri Star Concrete Products Factory LLC
Al Jaber Iron and Steel Foundry LLC
Cicon Epoxy & Steel Cutting Plant LLC
Galvacoat
Gulf Steel Industries Co. LTD LLC
Jindal Saw Gulf LLC
National Marine Dredging Company
Shurooq Gulf Steel and Cement Industries Establishment
Special Steels Factory LLC
Technical Metal Industrial Co.
Tiger Steel Industries LLC
Union Iron & Steel Company LLC
Weatherford Manufacturing and Services LLC
Emirates Aluminium Company Limited PJSC
Al Jaber Aluminium Extrusions LLC
Al Jazira Metal Industries Co. LLC
Dubai Cable Company Pvt. LTD Abu Dhabi (Branch 1)
Union Copper Rod LLC
Abba Botanical Preparations Factory
Abu Dhabi Fertilizer Industries Co. WLL
Air Liquide Emirates for Industrial Gases
Ajwaa Emirates Gases Co. LLC
Al Shefa Veterinary Medicines Factory LLC
Emirates Western Oil Well Drilling and Maintenance Factory LLC. (Industrial Branch)
Gulf Cryo Industrial Gases Company LLC
Gulf Fluor LLC
National Paints Factories Co. LLC (Abu Dhabi branch)
Neopharma LLC
Pan Gulf Labs Solutions Factory
Saad H. Abukhadra and Co.
Super Tech Dry Ice Manufacturing LLC
Tam Perfumes Factory
Union International Bitumen Co. LLC
Universal Paint and Chemical Industries Chemipaint LLC
Al Ahlia Gulf Line General Trading Company (PVT) Ltd LLC
Al Furat Drinking Water LLC
Al Redwan Pure Water
Alfoah Dates Factory
Alghadeer Drinking Water Factory
Golden Spike and Wheat EST
One Foods (Alwar Food Products Factory LLC)
Super Awafi Mineral Water Co. LLC
Warsan Animals Food Manufacturing (Al Ain Branch)
Abu Dhabi National Paper Mill LLC
Crown Paper Mill LTD (Abu Dhabi Branch)
Abu Dhabi Pipe Factory LLC
Abu Mansoor Plastic Factory
Al Mimari Industrial Co. LLC
Al Ain Acrylic Tubs Factory
Cosmoplast Industrial Co. LLC (Branch 1 of Abu Dhabi)
Electronic and Engineering Industries Co. LLC
Emirates Preinsulated Pipes Industries LLC
Integral Plastic Industries Co. LLC
Karemo Plastic Industry
M J Additive International Industry (SENTEC) LLC
Majestic Plast Plastic Industries
SHUAA Paper & Plastices Products Co.
Styropack For Plastic Factory LLC
Union Pipes Industry LLC
Emirates Printing Forms EST

Abu Dhabi Air Emissions Inventory 2018 Foreword

Air pollution was identified as a primary environmental threat to public health in the Abu Dhabi State of the Environment Report 2017. The Environment Agency-Abu Dhabi's (EAD) responsibility to take effective measures to mitigate man-made air emissions is more critical than ever before.

The Abu Dhabi Air Emissions Inventory, produced by EAD, represents a tremendous and concerted effort towards gaining a detailed understanding of man-made emissions across various sectors in the Emirate. Developed in partnership with key public and private stakeholders whose distinct industry insights form the basis of this report, the Inventory has helped produce over 50 high-definition sector and pollutant specific Air Emission Maps that identify the location and intensity of each emission source in Abu Dhabi - for the very first time. The report signifies a real milestone in EAD's Air Quality Monitoring programme that is helping us to counter the profound effects of air pollution on our wellbeing, as we progress to create a better environment for our people and planet.

The results of this inventory not only support us in monitoring and analysing information before we impose targeted regulations that will curb harmful emissions, but also lay the groundwork for crucial cross-sector collaboration to improve ambient air quality in Abu Dhabi. The Inventory will be a valuable resource as we take appropriate and integrated actions to ensure that all sectors comply with the relevant laws and policies pertaining to air emissions in the Emirate, allowing us to set the foundation for air quality modelling, establish a baseline for future planning and help set acceptable reduction targets.

This study will also prove instrumental when we evaluate and assess strategies currently in place to curb man-made air emissions. This data will help local municipalities in zoning and urban planning. It will also promote cost-effective initiatives to improve efficiencies and reduce emissions by providing baseline information on emissions from key economic sectors. Most importantly, the report will enable vital knowledge exchange with local and international experts and nurture a culture of cross-border research, which, in turn, will fuel science and innovation in environmental protection and sustainability in the UAE.

Razan Khalifa Al Mubarak
Secretary General

I would like to convey my sincere appreciation to our government partners including the Ministry of Climate Change and Environment, Statistics Centre – Abu Dhabi, Department of Transport, Department of Economic Development, Department of Urban Planning and Municipalities, Department of Energy, ADNOC and Abu Dhabi Ports, who together have played a defining role in the development of Abu Dhabi's first comprehensive air emissions geodatabase. The UAE Vision 2021 and Abu Dhabi Plan both stipulate that air quality should improve from its current levels to reach at least 90 per cent and 92 per cent respectively, and our collective contributions will go a long way in realising this improvement. This Air Emissions Inventory bolsters our commitment to preserving our environment for generations to come.

Contents

الملخص التنفيذي

التزمت حكومة إمارة أبوظبي بالحفاظ على البيئة والموارد الطبيعية في الإمارة في سبيلها نحو تحقيق الرفاهية لسكانها والحفاظ على قوة واستدامة اقتصادها من اجل الأجيال الحالية والمستقبلية. وقد ترجمة الإمارة هذا الالتزام من خلال وضع برنامج خاص حول «تحسين جودة الهواء والحد من تأثير التغير المناخي» وتضمينه في خطة أبوظبي (هيئة البيئة – أبوظبي، 2017). قام مشروع جرد انبعاثات ملوثات الهواء الرئيسية في إمارة أبوظبي بتطوير قوائم الجرد الخاصة بانبعاثات الملوثات في الإمارة بهدف دعم إدارة جودة الهواء فيها. ويعتبر هذا التقرير بمثابة خط الأساس لجميع انبعاثات ملوثات الهواء الرئيسية الحالية والذي سيسهم في وضع أفضل الاستراتيجيات والسياسات واللوائح التي ستؤدي إلى إدارة وتحسين نوعية الهواء في الإمارة.

وتتضمن قوائم جرد انبعاثات ملوثات الهواء الرئيسية في إمارة أبوظبي جميع المصادر الرئيسية للانبعاثات الناتجة عن الأنشطة البشرية ، والتي قد يكون لها تأثير على حدود ومعايير الملوثات المنصوص عليها في قرار مجلس الوزراء رقم 12 لعام 2006 المعني بحماية الهواء من التلوّث. ويتضمن تقرير الجرد ملوّثات رئيسية مثل أكاسيد النيتروجين (NO_X) وثاني أكسيد الكبريت (SO_2) والجسيمات الدقيقة العالقة في الهواء بنوعيها (PM_{10} و $PM_{2.5}$) وأول أكسيد الكربون (CO). كما وتمت إضافة المركبات العضوية المتطايرة غير الميثانية (NMVOC) الى مشروع الجرد وذلك نظرًا لدورها الكبير في تكون ملوث الأوزون الأرضي (O_3).

تتأثر جودة الهواء بعوامل محركة وضغوط تنشأ من مختلف القطاعات في مجتمعاتنا الحديثة بدءا من الإنبعاثات التي تطلقها مركباتنا الشخصية وصولا إلى الانبعاثات الناجمة عن قطاعاتنا الصناعية وأنشطة النفط والغاز. لذا وجب أن يتم الجرد الشامل للانبعاثات أخذين في الاعتبار جميع الأنشطة المحتملة التي قد تنبعث منها ملوثات الى هوائنا المحيط هادفين الى جمع أكبر كم من المعلومات والبيانات بهدف تقدير كمية الانبعاثات لكل ملوث على حده. ولإنجاز هذه الهدف عقدت هيئة البيئة – أبوظبي شراكات وثيقة مع خبراء عديدين من القطاعين الحكومي والخاص والذي لولا جهودهم ما كان لهذا المشروع ان يتم.

أحد أهم وأكبر التحديات التي واجهت عملية جرد الانبعاثات يتمثل في القدرة على جمع البيانات اللازمة لتقدير الانبعاثات باستخدام أفضل التقنيات وأكثرها دقة. أضف إلى ذلك وجد أن كل منشأة صناعية حاليا تعمل بموجب آليات ومنهجيات خاصة بها حسب حاجتها لجمع البيانات وإعدادها وبالتالي وجد ان لدى كل منشأة منهم بيانات وآليات إبلاغ تختلف عن بيانات وآليات إبلاغ المنشأة الأخرى. لذا وبعد التشاور مع شركائنا في مشروع الجرد ومن أجل الخروج بجرد شامل متكامل للانبعاثات الرئيسية في الإمارة تم الاتفاق وتحديد العام 2015 ليكون سنة الأساس للمشروع.

ويهدف جرد انبعاثات ملوثات الهواء الرئيسية في إمارة أبوظبي إلى تقدير هذه الانبعاثات ضمن أعلى معايير الدقة في ضوء المعلومات والبيانات المتاحة. ولذلك تمت الاستعانة بأفضل الممارسات والأساليب الدولية لتنفيذ هذا المشروع من حيث اختيار دليل جرد الانبعاثات الخاص بالبرنامج الأوروبي للرصد والتقييم (EMEP) ووكالة البيئة الأوروبية (EEA) ليكون المرجع والمبدأ التوجيهي الرئيسي لتقدير الانبعاثات. وكان الهدف من هذا الاختيار هو استخدام أحدث معاملات الانبعاث (EF) المتاحة مع الالتزام بطريقة موحدة ومنسقة لجرد هذه الانبعاثات. علاوة على ذلك وكما هو موضح في هذا التقرير، تمت الاستعانة بتوصيات من أدلة ممارسات دولية أخرى مثل دليل وكالة حماية البيئة الأمريكية وذلك لتغطية قطاعات وتقنيات ا غير مشمولة في الدليل السابق ذكره.

تتدرج مشكلة تلوّث الهواء ضمن القضايا البيئية والاجتماعية المعقدة المحملة بالعديد من الصعوبات والتحديات. وتختلف الانبعاثات التي تنتجها الأنشطة البشرية من حيث درجات تركيزها وكثافتها وانبعاثها في مختلف مناطق الإمارة. وعليه كان من المهم تحديد مواقع ومصادر هذه الانبعاثات ودرجة كثافتها ليكون المفتاح الأهم لتحديد كمية الانبعاثات ومدى تعرّض السكان والنظام البيئي لهذه الملوثات، حيث تعتبر هذه المعرفة هامة جدا في ضمان إدارة المشكلة والحد منها بالشكل المناسب. تخلّل هذا المشروع بذل الجهود الكبيرة لتحديد المواقع الجغرافية للانبعاثات في إمارة أبوظبي وذلك باستخدام أحدث التقنيات المتاحة مثل صور الأقمار الصناعية عالية الوضوح ونماذج حركة المرور وأنظمة المعلومات الجغرافية (GIS).

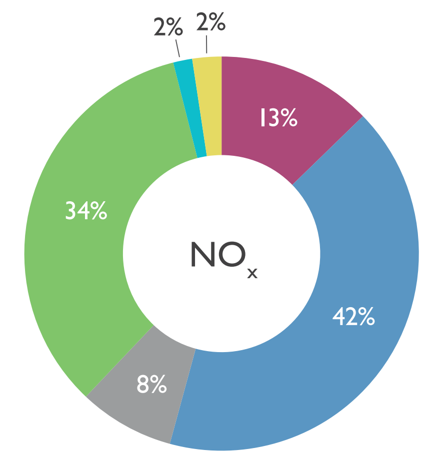
وقد تم جمع البيانات والتحقق منها وحفظها ضمن قاعدة بيانات جغرافية معيارية. ويتضمن ذلك تحديد موقع كل مصدر من مصادر الانبعاثات بدقة عالية مثل محطات توليد الطاقة وتدفقات حركة المرور في الطرق والأنشطة المرتبطة بالنفط والغاز وعمليات التصنيع وأنشطة الاحتراق ومحطات التزود بالوقود. كما تم تطوير خرائط مفصلة لتمثيل مصادر الانبعاثات من حيث القطاعات كما في (الشكلان 2 و 3)

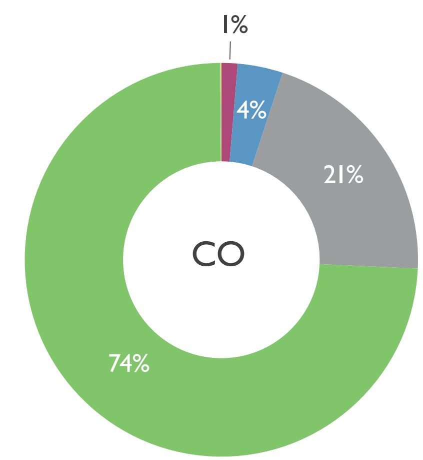
وحتى يتسنى توفير صورة أوضح للانبعاثات في كل منطقة، أعد فريق المشروع خرائط انبعاثات عالية الوضوح (الشكل 4). توضح هذه الخرائط كميات الانبعاثات السنوية بدقة عالية جدا بمساحة تصل حتى (1 كم في 1 كم) لكل ملوث وذلك بإتباع أفضل الممارسات الدولية. يمكن الإطلاع على خرائط أكثر تفصيلًا لكل ملوث في الشكلين 10 و 15 من هذا التقرير.

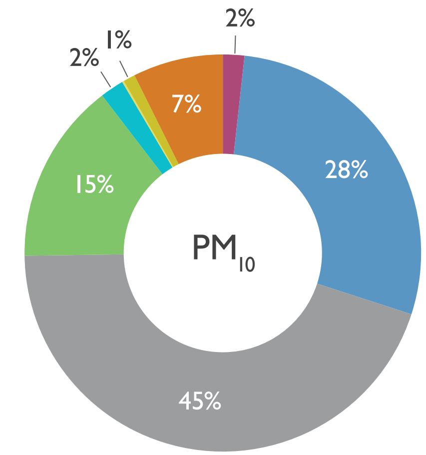
كانت النتائج الرئيسية حول موقع كل مصدر وكثافة إنبعاثات الملوثات الناتجة عنه في الإمارة كما يلي:

- أكاسيد النيتروجين (NO_X): تتركز معظم الانبعاثات على طول مناطق النقل المختلفة (شبكات الطرق والموانئ والمطارات) وفي مناطق الصناعات الكبيرة مثل الحديد والصلب والصناعات الأسمنتية ، كما ويتركز هذا الملوث في مناطق أنشطة النفط والغاز ومحطات توليد الكهرباء وتحلية المياه.
- ثاني أكسيد الكبريت (SO_2): تقع أكبر كمية انبعاثات بالقرب من أنشطة النفط والغاز البرية والبحرية، وكذلك بالقرب من مصانع الألومنيوم ومناطق الموانئ الرئيسية.
- أول أكسيد الكربون (CO): تنبعث أغلب كميات هذا الغاز من المناطق القريبة من شبكات الطرق الرئيسية والمناطق الصناعية.
- المركبات العضوية المتطايرة غير الميثانية (NMVOC): تنبعث هذه المركبات من مناطق أنشطة النفط والغاز وبالقرب من الطرق الرئيسية.
- الجسيمات الدقيقة العالقة في الهواء ذات الحجم 10 مايكرون (PM_{10}) و الجسيمات الدقيقة العالقة في الهواء ذات الحجم 2.5 مايكرون ($PM_{2.5}$): نجد بأن أغلب الانبعاثات تتمركز في المناطق الصناعية وبالقرب من المناطق ذات الحركة المرورية الكثيفة ومناطق أنشطة النفط والغاز البحرية.

توضح جميع النتائج المذكورة آنفا مدى تعقيد مشكلة انبعاثات ملوثات الهواء في إمارة أبوظبي الأمر الذي يتطلب منهجًا إداريًا يتقاطع مع جميع القطاعات في الإمارة، ويقوم على جهود مشتركة وتعاون وثيق بين مختلف الجهات الحكومة والقطاع الخاص. كما ويجب الإشارة هنا الى ان أحد أهم عوامل نجاح هذا المشروع الرئيسية كان التعاون والشراكة الوثيقة بين جميع الجهات المعنية في الإمارة، والذي أثمر عن بناء شراكات ديناميكية معهم، والذي نوصي هنا باستمراريتها مستقبلا وذلك بهدف تحديث قوائم جرد انبعاثات ملوثات الهواء في السنوات القادمة بشكل مستمر لا سيّما وأن هذا المشروع يعتبر من أهم المحاور الرئيسية في برنامج إدارة جودة الهواء في إمارة أبوظبي. هذا وستوفر هذه الشراكة المستمرة بين الجهات المعنية معلومات أساسية لتصميم ووضع إجراءات ونظم قياس ذات أسس علمية كفيلة بتقليل هذه الانبعاثات، وهو ما يدعم رؤية قيادة إمارة أبوظبي الرامية إلى تعزيز جودة الحياة وتشجيع التنمية المستدامة في الإمارة.







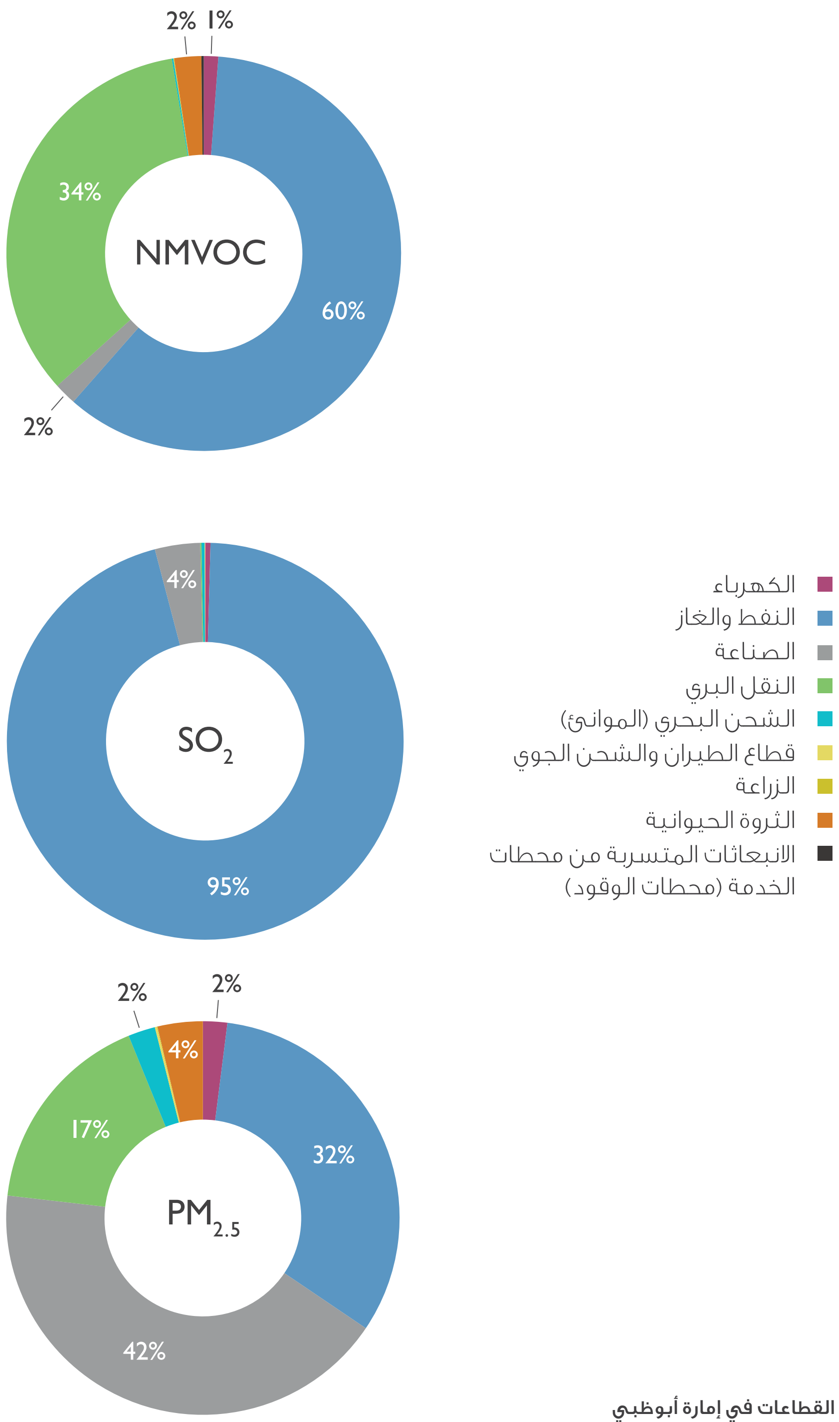
الملخص التنفيذي

أظهرت النتائج أن إجمالي الانبعاثات من الكهرباء والنفط والغاز والصناعات والنقل البري والشحن البحري والطيران والزراعة والثروة الحيوانية والانبعاثات المتسربة من محطات الخدمة (محطات الوقود) في إمارة أبوظبي للعام **2015** بلغت التالي:

- 105,986 طن من أكاسيد النيتروجين (NO_X)
- 9,888 طن من الجسيمات الدقيقة العالقة في الهواء ذات الحجم ١٠مايكرون (PM_{10})
- 8,604 طن الجسيمات الدقيقة العالقة في الهواء ذات الحجم 2.5 مايكرون ($PM_{2.5}$)
- 370,732 طن من ثاني أكسيد الكبريت (SO_2)
- 594,813 طن من أول أكسيد الكربون (CO).
- 102,258 طن من المركبات العضوية المتطايرة غير الميثانية (NMVOC)

مساهمة كل قطاع من الانبعاثات لكل ملوث موضحة في الشكل أدناه
يوضح الشكل ١ المخرجات الرئيسية من حيث القطاع والملوث:

- 42% من انبعاثات أكاسيد النيتروجين من النفط والغاز، و 34% من النقل البري و 13% من توليد الكهرباء.
- ساهم قطاع النفط والغاز في أغلبية انبعاثات ثاني أكسيد الكبريت ما نسبته (95%) وبنسبة 60% من انبعاثات المركبات العضوية المتطايرة غير الميثانية (NMVOC)
- ساهم قطاع النقل البري بأغلبية انبعاثات أول أكسيد الكربون بما نسبته (74%).
- نتجت أغلبية انبعاثات الجسيمات الدقيقة العالقة في الهواء بنوعيها ذات الحجم 10 مايكرون (PM_{10}) و ذات الحجم 2.5 مايكرون ($PM_{2.5}$) من العمليات التصنيعية بنسبة 45% للأولى و42% للثانية. بينما ساهم النقل البري بانبعاث ما نسبته 15% من الجسيمات الدقيقة العالقة في الهواء ذات الحجم 10 مايكرون (PM_{10}) و 17% من الجسيمات الدقيقة العالقة في الهواء ذات الحجم 2.5 مايكرون ($PM_{2.5}$)، وقطاع النفط والغاز بنسبة 28% من الجسيمات العالقة في الهواء ذات الحجم 10 مايكرون (PM_{10}) و 32% من الجسيمات الدقيقة العالقة في الهواء ذات الحجم 2.5 مايكرون ($PM_{2.5}$).



الشكل: ١ خرائط انبعاثات جميع القطاعات في إمارة أبوظبي

Executive Summary

Abu Dhabi Government is committed to preserving the emirate's environment and natural resources in order to maintain the wellbeing of its people and the strength of its economy for present and future generations. This commitment has been reflected in the Abu Dhabi Plan, which includes a specific programme to "Improve air quality and limit the impacts of climate change" (EAD, 2017). The emissions inventory for criteria pollutants in Abu Dhabi Emirate has been developed to support Abu Dhabi air quality management. This report is developed to be a baseline of the current emissions in the emirate and to help in designing the most appropriate strategies, policies and regulations that will lead to an improvement in air quality.

The Abu Dhabi Air Emission Inventory includes all the major sources of man-made emissions in the emirate that may have an influence on the criteria pollutants specified in the UAE Cabinet Decision No. (12) of 2006 Concerning Air Protection from Pollution. Pollutants included in this inventory are nitrogen oxides (NO_X), sulphur dioxide (SO_2), particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO). Additionally, non-methane volatile organic compounds (NMVOC) have also been included due to their role in ground-level ozone (O_3) formation.

The drivers and pressures that affect air quality derive from different sectors of our modern society: from the emissions of our personal cars to the emissions of our industrial sector and oil and gas industry. Therefore, a comprehensive emission inventory must take into consideration all the potential activities that may emit air pollutants to the atmosphere, and compile a considerable amount of information in order to estimate the emissions for each specific pollutant. In this task Environment Agency – Abu Dhabi partnered with the local government and private sectors' experts, without whom this project would not be possible.

One of the biggest challenges of any emission inventory is to collect the data needed to estimate the emissions using the most accurate techniques. Besides, each entity has its own individual data needs and therefore individual data reporting mechanisms and reporting frequency. After consultation with our stakeholders, and in the interest of getting the most complete Air Emissions Inventory, 2015 was set as the base year.

The objective of the Air Emissions Inventory is to estimate emissions at the level that involves the lowest uncertainty, given the available information. Therefore, the best international practices and methods were used in this project: the EMEP/EEA Emission Inventory Guidebook (2016) was selected as the main guideline for emission estimates, with an aim to use the most recent emission factors available and to keep the method of the emission inventory consistent. Moreover, for sectors or technologies not covered by these guidelines, other recommendations were used as described in detail in this document, such as the US EPA methods and guidelines.

Executive Summary

Results showed that for the year 2015 in Abu Dhabi Emirate, emissions from electricity, oil and gas, industry, road transport, shipping, aviation, agriculture, livestock and fugitive emissions at service stations (petrol stations) totalled:

- 105,986 t NO_X
- 9,888 t PM_{10}
- 8,604 t $PM_{2.5}$
- 370,732 t SO_2
- 594,813 t CO
- 102,258 t NMVOC

The contributions to emissions from each sector for each pollutant are presented in Figure 1. The main outcomes by sector and pollutant are:

- 42 % of nitrogen oxides (NO_X) emissions derived from oil and gas, 34 % from road transport, and 13 % from electricity generation;
- The oil and gas sector contributed the majority (95 %) of sulphur dioxide (SO_2) and 60 % of non-methane volatile organic compound (NMVOC) emissions;
- The road transport sector contributed the majority (74 %) of carbon monoxide (CO) emissions; and
- For both PM_{10} and $PM_{2.5}$, most emissions derived from industrial processing (45 % and 42 % respectively), road transport (15 % and 17 % respectively), and oil and gas (28 % and 32 %, respectively).

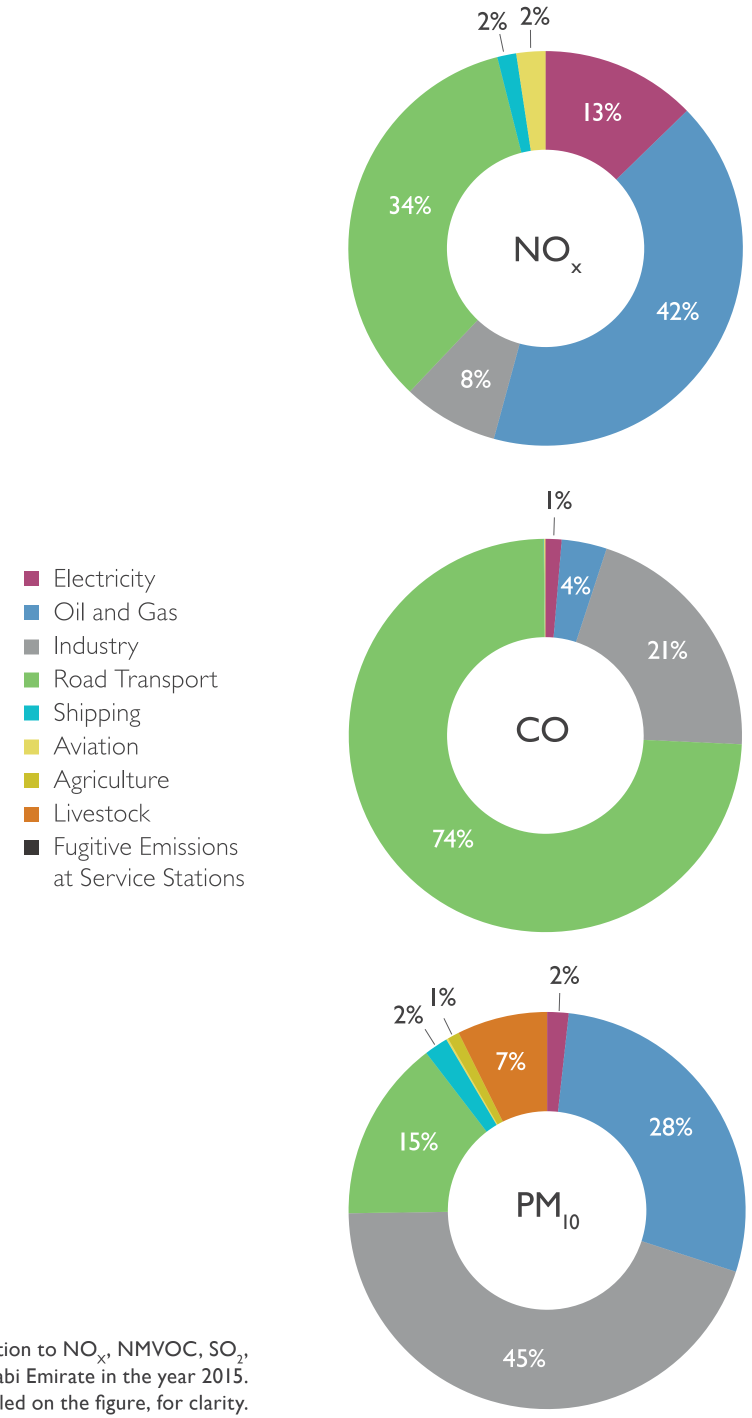
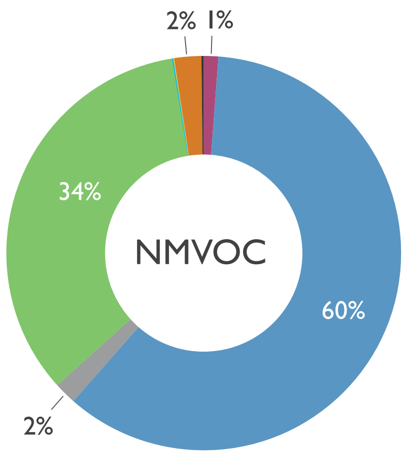
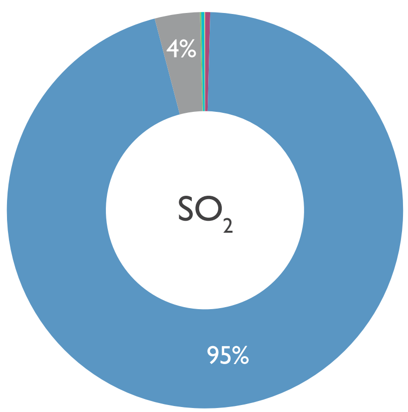
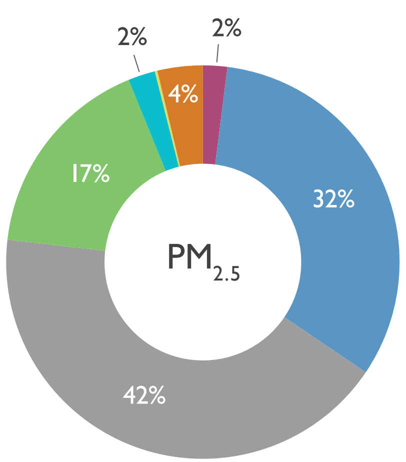


Figure 1: Summary of sectoral contribution to NO_X, NMVOC, SO_2, CO, PM_{10} and $PM_{2.5}$ emissions in the Abu Dhabi Emirate in the year 2015. Note: Contributions less than 1 % are not labelled on the figure, for clarity.







Air pollution is a complex environmental and social issue, with multiple challenges. Anthropogenic emissions are emitted with different intensities in each part of the emirate. Identifying the location and intensity of the emission sources is key to quantifying the exposure of the population and ecosystems. This knowledge is also important in guaranteeing proper management and mitigation.

In this project major efforts went into geolocating the emissions in Abu Dhabi Emirate, using the most advanced techniques such as high definition satellite imagery, traffic modelling, and geographic information systems (GIS).

All the available data has been collected, validated and stored in a standardised geographic information database. This includes the precise location of each emission source, such as: the power plants; the traffic flow for each road segment; the oil and gas activities; the industrial process and combustion activities; and the petrol stations.

Detailed maps have been created to represent the emission sources by sector (Figure 2 and Figure 3). In order to provide a clear picture of the emissions in each area, high definition emission maps have been developed as part of this project (Figure 4). These maps show the annual amount of emissions in a high resolution grid of 1 by 1 km, following international best practices. More detailed maps for each pollutant can be found from Figure 10 to Figure 15 of the document.

The main conclusions about the location and intensity of the sources for each pollutant are:

- Nitrogen oxides (NO_x): most of the emissions are located along the transportation areas (road network, ports and airports zones); in the big metal industries and cement production industries; in the oil and gas areas; and in the electricity and water desalination plants.
- Sulphur dioxide (SO_2): the largest amount of emissions are located in the offshore and onshore oil and gas activities; in the key aluminium industries and in the main ports area.
- Carbon monoxide (CO): the CO emissions are mostly emitted near the main road network; and in the industrial areas.
- Non-methane Volatile Organic Compounds (NMVOC): are emitted in the oil and gas areas and near the main roads.
- Particulate matter (PM_{10} and $PM_{2.5}$): the main emission can be found in the industrial areas; near the areas with high road traffic; and in the offshore oil and gas activities.

These conclusions show the complexity of the air emissions in Abu Dhabi Emirate. This complexity will require a management approach that is cross-sectoral, with joined efforts and close collaboration between government entities and the private sector. One of the key successes of this project is the strong stakeholder engagement that led to dynamic partnerships with all the relevant sectors. These partnerships are encouraged to continue in the future updates of the Air Emission Inventory, a key pillar of the Air Quality Management in Abu Dhabi Emirate.

This continuous partnership will provide essential information for designing science-based measures to reduce emissions. This will support Abu Dhabi leadership's vision to enhance Abu Dhabi's quality of life and promote sustainable development.

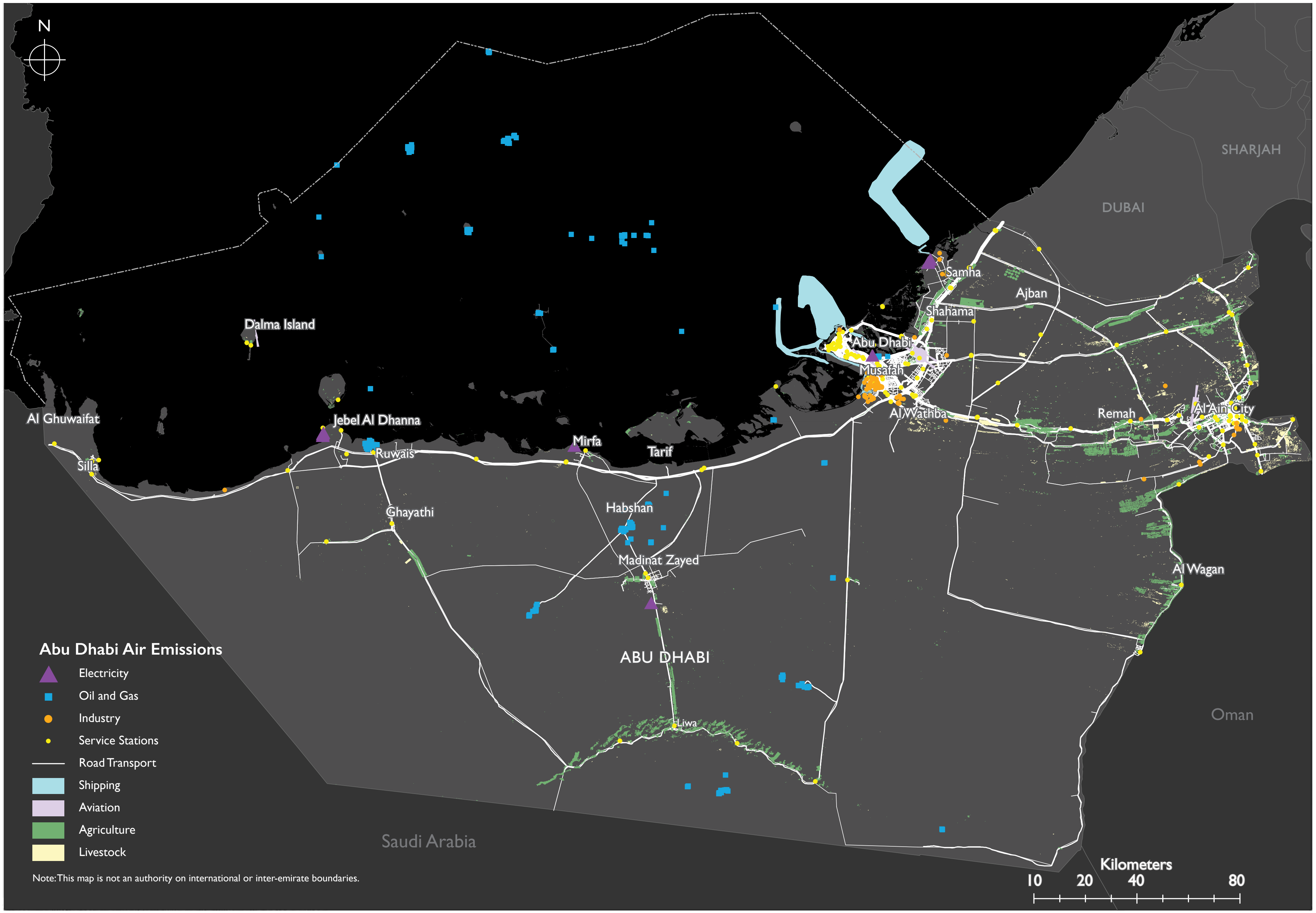
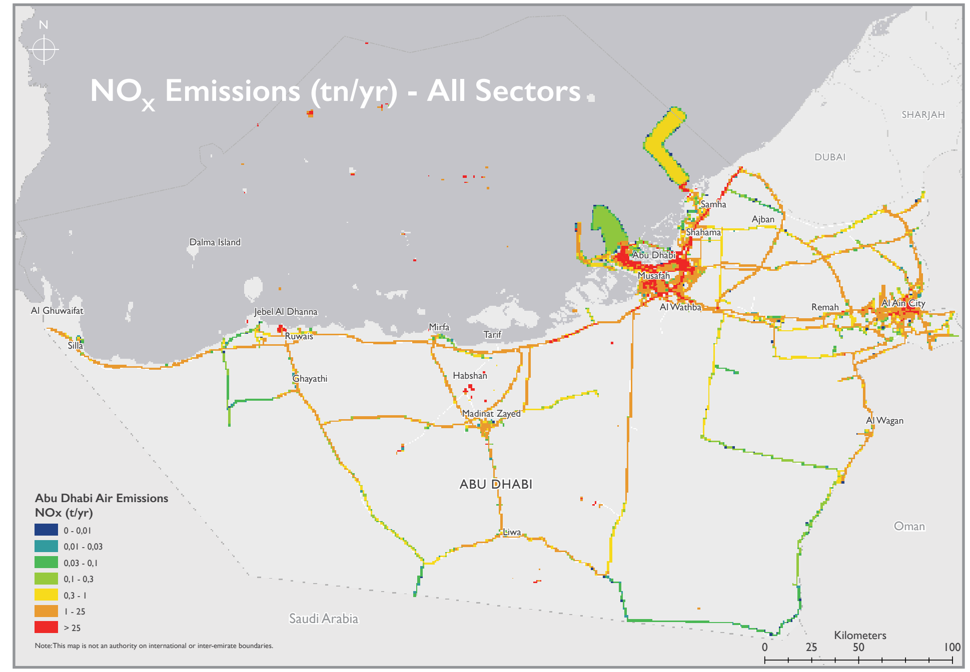
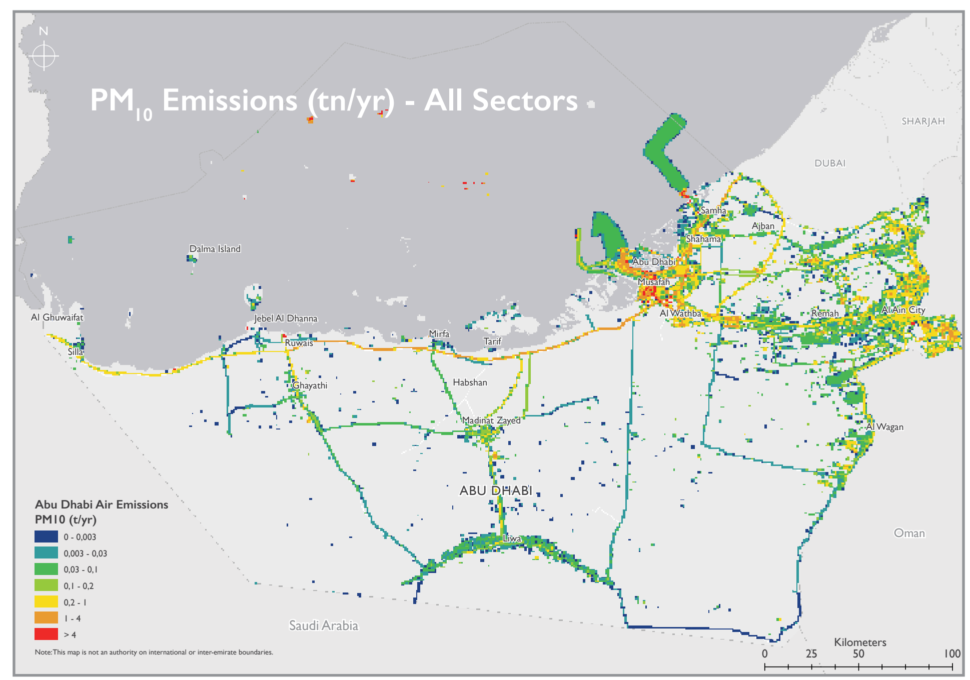


Figure 2: Location of the emission sources by sector in Abu Dhabi Emirate.

Figure 3: Location of the emission sources by sector in Abu Dhabi Emirate (zoom in Abu Dhabi Island).



N
NOx Emissions (tn/yr) - All Sectors
SHARJAH
DUBAI
Samha
Ajban
Shahama
Abu Dhabi
Mussafah
Al Wathba
Remah
Al Ain City
Dalma Island
Al Ghuwaifat
Sila
Jebel Al Dhanna
Ruwais
Mirfa
Tarif
Ghayathi
Habshan
Madinat Zayed
Al Wagan
ABU DHABI
Liwa
Oman
Saudi Arabia
Abu Dhabi Air Emissions
NOx (t/yr)
0 - 0,01
0,01 - 0,03
0,03 - 0,1
0,1 - 0,3
0,3 - 1
1 - 25
> 25
Note: This map is not an authority on international or inter-emirate boundaries.
Kilometers
0 25 50 100



N
PM10 Emissions (tn/yr) - All Sectors
SHARJAH
DUBAI
Samha
Ajban
Shahama
Abu Dhabi
Mussafah
Al Wathba
Remah
Al Ain City
Dalma Island
Al Ghuwaifat
Sila
Jebel Al Dhanna
Ruwais
Mirfa
Tarif
Ghayathi
Habshan
Madinat Zayed
Al Wagan
ABU DHABI
Liwa
Oman
Saudi Arabia
Abu Dhabi Air Emissions
PM10 (t/yr)
0 - 0,003
0,003 - 0,03
0,03 - 0,1
0,1 - 0,2
0,2 - 1
1 - 4
> 4
Note: This map is not an authority on international or inter-emirate boundaries.
Kilometers
0 25 50 100

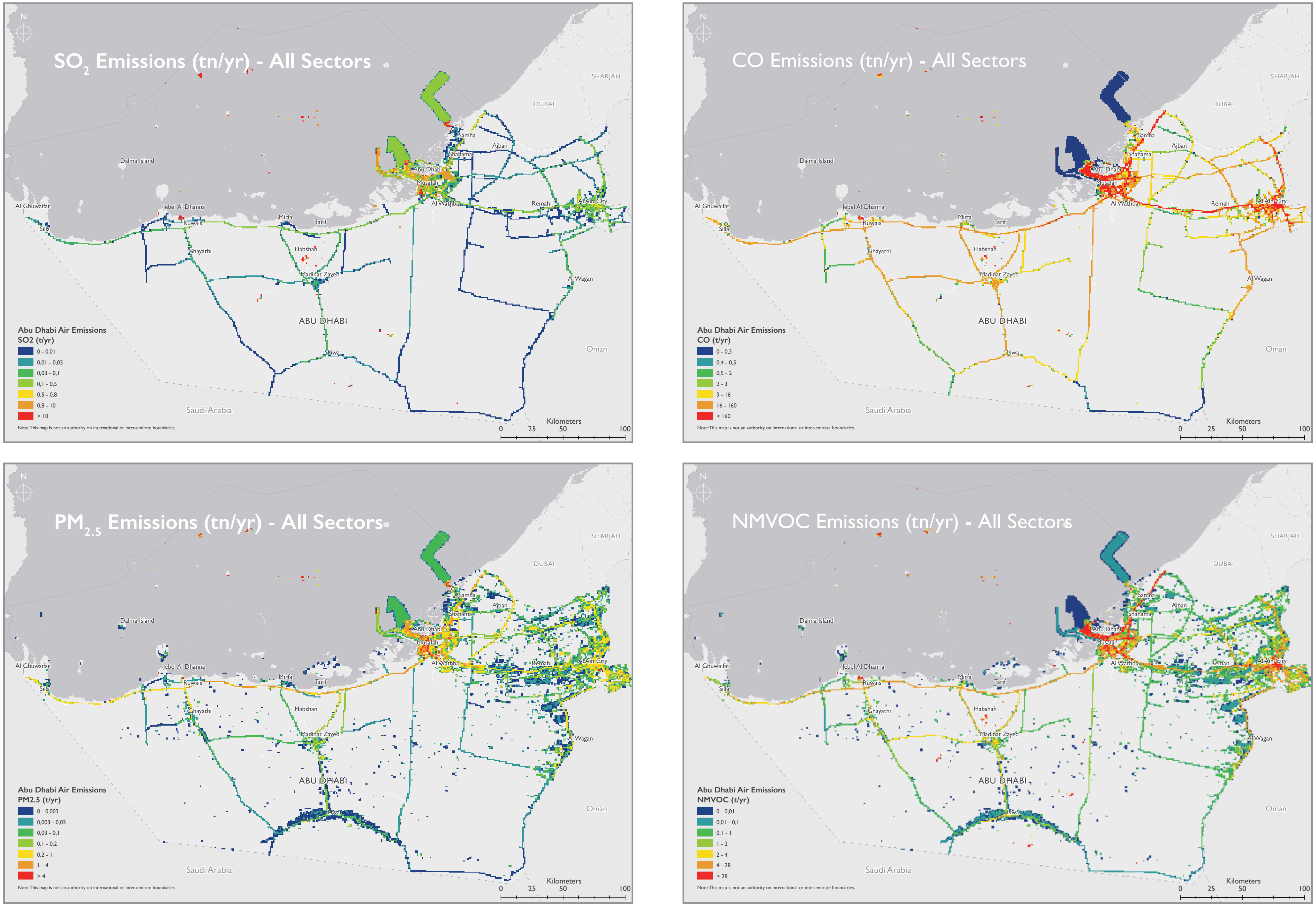


Figure 4: Emission maps of all sectors in Abu Dhabi Emirate

Introduction

1 Introduction

1.1 Abu Dhabi Emirate - Local Conditions

1.1.1 Geography and Climate

The Abu Dhabi Emirate is one of seven emirates that constitute the United Arab Emirates (UAE). It is the largest of the Emirates (Figure 5) covering 67,340 km2, approximately 86 % of the UAE territory. The UAE lies within the northern desert belt of the Arabian Peninsula, and the Abu Dhabi Emirate is situated on its north-eastern part, bordering the Kingdom of Saudi Arabia and the Sultanate of Oman, and the Dubai and Sharjah Emirates (Figure 5).

Figure 5: Location of the Abu Dhabi Emirate and border territories.

The Emirate of Abu Dhabi is located in a tropical dry region, with an arid nature characterised by high temperatures through the year and hot summers that are associated with high relative humidity. The air temperatures show variations according to the topography, and differences are observed between coastal areas, desert interiors and high elevations (Figure 6). Precipitation varies from year to year with an average rainfall below 100 mm annually, although this is regionally specific. Highest rainfall occurs during winter (Figure 7).

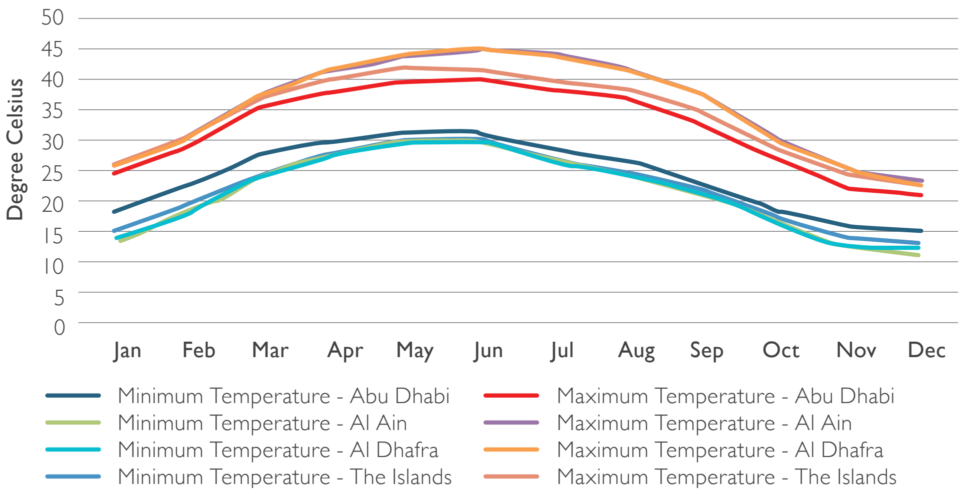


Figure 6: Average maximum and minimum monthly air temperature by region, 2015 (Source SCAD, 2016). Note: Al Gharbia region has changed name to Al Dhafra region.

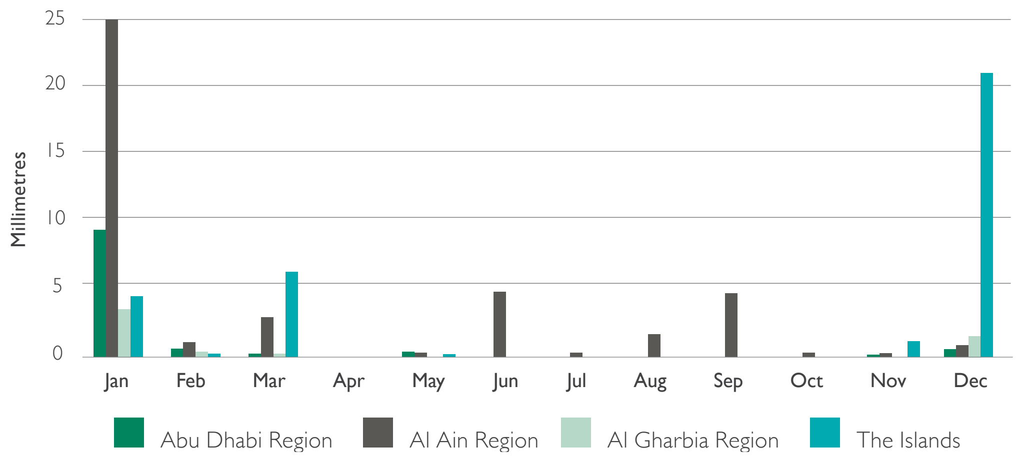


Figure 7: Average monthly rainfall by regions in Abu Dhabi Emirate, 2015 (Source SCAD, 2016). Note: Al Gharbia region has changed name to Al Dhafra region.

1.1.2 Demography

Based on the data published by Statistics Centre - Abu Dhabi (SCAD), the population of Abu Dhabi Emirate in the year 2015 was estimated as 2,784,490 (SCAD, 2016), and has experienced an annual population growth rate of 7.3 % since 2005. The Abu Dhabi Region holds 61.8 % of the population, followed by Al Ain Region (26.5 %) and Al Dhafra Region (11.7 %). Of the total Abu Dhabi Emirate population, 19.3 % are Emirati citizens. The population density of Abu Dhabi Emirate in 2015 was estimated to be 46.8 person/km^2.

1.1.3 Economy

The main contribution to the revenue of the Abu Dhabi Emirate is from mining and quarrying (predominantly crude oil and natural gas). The UAE has a large wealth of hydrocarbons, with the majority owned by Abu Dhabi Emirate (95 % of UAE oil and 92 % of UAE natural gas (Kapur, 2010)). Creating strategies to ensure development and reform towards a diversified economy in the Emirate of Abu Dhabi are amongst the key objectives of the supreme leadership of the Emirate. The sustained focus on these and other supporting objectives, combined with the competitive edge the Emirate enjoys, has placed Abu Dhabi's economy in a strong position, regionally and internationally. In recent years, the government has looked to diversify the economy.

The economy of Abu Dhabi Emirate is growing, with the gross domestic product (GDP) increasing to 770,011 million United Arab Emirate Dirham (AED) in 2015, from 678,049 million AED in 2012 (SCAD, 2017; with GDP in constant 2007 prices). According to SCAD (2017), in 2015 GDP from oil and gas contributed 35 % of total GDP (including mining and quarrying). Construction and manufacturing were the second and third largest contributors towards total Emirate GDP, with 11.4 % and 6.4 % of total GDP, respectively.

1.2 Abu Dhabi Commitment to Improve Air Quality

The UAE National Agenda leading to the Vision 2021 focuses on improving the quality of air as one of its priority areas, aiming to ensure sustainable development while preserving the environment, and to achieve a perfect balance between economic and social development. To measure progress, the Agenda provides an Air Quality Indicator, which measures the quality of air in terms of supplying daily information on pollution and the negative effects it may have on human health. The indicator measures the four main air pollutants: nitrogen dioxide, carbon monoxide, sulphur dioxide and ozone. For 2016, the indicator for UAE was estimated to be 76 % of green days[1].

Air pollution had been identified as the single biggest environmental threat to the health of people and wildlife in the emirate of Abu Dhabi (MacDonald Gibson et al., 2013). To protect water, air and land is a priority of the EAD. A comprehensive monitoring Programme for criteria pollutants is already in place since 2007, with the overall aim to fulfil the UAE legislative obligations and to ensure the appropriate quality of air for all inhabitants of the Emirate. The monitoring network covers Abu Dhabi Region, Al Ain Region, and Al Dhafra Region, and industrial areas such as Mussafah. Air quality is evaluated based on the data collected from the monitoring network and compared with the allowed limits provided in *UAE Cabinet Decision No. (12) of 2006 concerning air protection from pollution.* The network consists of 20 fixed and two mobile stations, giving information on sulphur dioxide, carbon monoxide, nitrogen dioxide, ozone, particulate matter (PM10 and PM2.5), hydrogen sulphide, methane, BTEX (benzene, toluene, ethyl benzene and xylene), and selected meteorological parameters.

In order to take action regarding improvement of air quality, the EAD carries out a number of additional activities that aim to support air quality management. A successful air quality management has to be underpinned by good quality information on air quality (a monitoring network being the most important element of information gathering), and on emissions to air.

The Abu Dhabi objectives in the area of air quality for the period 2016-2020 are (EAD, 2016a):

- To establish effective coordination mechanisms with key stakeholders and to align common policies and plans for air quality;
- To strengthen the legal and regulatory framework for air quality;
- To build a strong and comprehensive understanding and improve analysis of ambient air quality; and
- To work with relevant stakeholders to educate and advance knowledge on air quality.

This report documents a significant contribution to these objectives.

1. Accessed December 2017.

1.3 About this Report

1.3.1 Overview

This report was developed with the overall aim of describing the emission inventory for criteria pollutants in Abu Dhabi Emirate for 2015. The report was developed with a focus on the methods selected to estimate emissions for each sector, the input data and their sources, assumptions and the emission estimates. NILU – Norwegian Institute for Air Research (NILU) carried out the scientific and technical work and was responsible for the methods for emission inventorying including the data collection questionnaires. The Environment Agency – Abu Dhabi (EAD) oversaw the complete project development, enhancement of the questionnaires, reviewed the report and emission estimation, and facilitate the contact with internal and external stakeholders, as well as organised numerous stakeholder consultations and reviews.

The emission inventory includes nitrogen oxides (NO_X), sulphur dioxide (SO_2), particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOC). Based on an assessment of data availability, expert opinion and communication with the Environment Agency - Abu Dhabi (EAD), specific sectors were selected and prioritized. The structure of this report reflects the sectorial division, according to 1) Electricity production; 2) Oil and gas production; 3) Industrial processing; 4) Road transport; 5) Shipping; 6) Aviation; 7) Agriculture; 8) Livestock; and 9) Fugitive emissions at service stations.

1.3.2 Objectives

The overall aim of the project "Update Emission Inventory for criteria pollutants" is to provide an updated emission inventory for criteria pollutants in Abu Dhabi Emirate for 2015, thus updating the previous inventory done for the year 2009 (John and Daham, 2009). The work of the project has been carried out whilst fulfilling the following objectives:

- To identify the main contributing sectors (Table 1);
- To set the foundation for air quality modelling;
- To establish a baseline for future planning;
- To support setting emission limits and reduction targets;
- To track environmental performance of individual sectors and entities;
- To design effective mitigation measures;
- To generate public interest in air quality.

Table 1: Emission sources for the Abu Dhabi Air Emissions Inventory.

Emission Source	
Oil and gas	Exploration and production Processing and refining
Electricity and water	Electricity production and water desalination facilities
Industry	Asphalt production facilities Cement production facilities Concrete and ready-mix production facilities Iron and steel production facilities Aluminium production facilities Copper production facilities Chemical production facilities Food and beverage production facilities Paper production facilities Plastic production facilities Printing facilities

Road transport	Shipping	Aviation	Agriculture	Livestock	Fugitive emissions at service stations

1.3.3 Air Pollutants

Sulphur Dioxide (SO_2)

SO_2 is a product of combustion processes and the largest source in the atmosphere is the burning of fossil fuels by power plants and industrial facilities, followed by smaller emission sources such as 1) industrial processes such as extracting metal from ore, 2) ships, vehicles and heavy equipment fuelled with high sulphur content fuel, or 3) natural sources such as volcanoes. Emissions that lead to high concentrations of SO_2 in the atmosphere also lead to the formation of other sulphur oxides (SO_X) and subsequent formation of small particles. SO_2 affects both human health and the environment. Short-term exposure to SO_2 can have harmful effects in the human respiratory system and cause breathing difficulties. Moreover, SO_2 and other sulphur oxides contribute to acid rain and harming ecosystems.

Carbon Monoxide (CO)

Carbon Monoxide is emitted during combustion processes. The greatest source of CO is road transport (vehicles) along with other machinery that combusts fossil fuels. CO has significant harmful effects on human health. Breathing air with a high concentration of CO reduces the amount of oxygen in the blood, affecting critical organs like the heart and brain. High concentration of CO is especially relevant for people with some types of heart disease.

Nitrogen Oxides (NO_X)

Nitrogen oxides (NO_X) is the sum of nitric oxide (NO), nitrogen dioxide (NO_2) and other oxides of nitrogen. Outdoors NO_X comes mainly from combustion related anthropogenic emissions sources, such as primary fossil fuel combustion in electricity production, industrial processes at high temperature and road transport. NO_2 is of great concern for human health. At high pollution levels, it affects the respiratory system causing inflammation of the airways, increasing the risk of respiratory conditions and the response to allergens. Exposure over short periods can aggravate respiratory diseases, such as asthma, and respiratory symptoms such as coughing, wheezing, or difficulty breathing.

NO_X reacts with volatile organic compounds in the presence of sunlight to form ozone, which is also harmful for human health and has ecological effects. Moreover, NO_X reacts with other chemicals in the air to form PM (nitrate particles). One of the most important environmental effects associated with NO_X is the acid rain as a result of its interaction with water and oxygen. Acid rain harms sensitive ecosystems such as lakes and forest.

Non-Methane Volatile Organic Compounds (NMVOC)

Non-methane volatile organic compounds (NMVOCs) are a group of organic compounds that differ in their chemical composition but have similar behaviour in the atmosphere. The main sources of NMVOCs are combustion activities, particularly road transport, solvent use and industrial production processes. NMVOCs contribute to the formation of ozone, and therefore harmful to human health and ecological effects. Some of the compounds (e.g. benzene, 1,3 butadiene) are harmful to human health, and have been shown to be carcinogenic at high pollution levels.

Particulate Matter ($PM_{2.5}$ and PM_{10})

Particulate matter (PM) consists of microscopically small solid particles or liquid droplets suspended in air. Exposure to PM pollution has been clearly linked to negative effects in human health, ecosystems and materials, and also high PM levels deteriorate visibility. Primary PM derives from a wide range of both anthropogenic and natural sources, including traffic, industry, as well as dust from construction sites and transport from desert areas. Secondary particles are formed as a product of the reactions between precursor gases and atmospheric oxidants.

Airborne particles cover a wide range of sizes. Regarding adverse effects on human health, concerns exist on PM with an aerodynamic diameter of less than 10 µm (PM_{10}) and 2.5 µm ($PM_{2.5}$). PM_{10} can penetrate into the respiratory tract and $PM_{2.5}$ into the gas-exchange region of the lung. Coarse particles ($PM_{10-2.5}$) are mainly linked to respiratory outcomes and $PM_{2.5}$ with cardiovascular diseases.

1.4 Emission estimates – General Description

Emissions have been calculated based on the combination of data regarding a human activity (A) and a coefficient that quantifies the emissions per unit of activity, commonly known as an emission factor (EF).

$$\text{Emissions} = \text{Activity (A)} \times \text{Emission Factor (EF)} \qquad \textit{Equation 1}$$

This basic equation can be modified to account for factors that may affect emissions, such as the installation of abatement control measures in the industrial sector, or ageing factors for combustion technologies affecting on-road traffic emissions.

For the update of the emission inventory in Abu Dhabi Emirate, the EMEP/EEA Emission Inventory Guidebook (2016) has been selected as the main guideline. The EMEP/EEA guidebook states that emissions can be estimated at different levels, which are expressed as three tiers of increasing complexity. Accordingly, tier 1 is based on statistical activity rate and default emissions factors; tier 2 uses more specific information, for instance specific emission factors per type of process or technology; and tier 3 involves a greater level of disaggregation of activity data and emissions factors than tier 2. The methods used in our study and the data collected are evaluated taking into account these levels of complexity, as higher level (tier 3) would involve a lower uncertainty.

Specific methods for calculations in each sector are given in more detail in each section.

1.4.1 Project Stakeholders

Along all the project there has been a continuous consultation with our stakeholders, for data collection and coordination, review and evaluation. Local capacity-building was also one of the key objectives of the project, which had the added benefit to improve the quality of the received data and emission estimates.

Key project stakeholders included the following:

- Ministry of climate change and Environment (MOCCAE)
- Ministry of Energy (MOENR)
- Department of Urban planning and municipalities (DPM)
- Department of Health (DoH)
- Department of Transport (DOT)
- Abu Dhabi Airports Company (ADAC)
- Abu Dhabi Police
- Abu Dhabi Ports (ADP)
- Abu Dhabi Food Control Authority (ADFCA)
- Abu Dhabi National Oil Company (ADNOC)
- Abu Dhabi Sewerage Services Company (ADSSC)
- Abu Dhabi Water & Electricity Authority (ADWEA)
- Centre of Waste Management – Abu Dhabi (CWM)
- EAD-RTI International
- Emirates Global Aluminium (EGA)
- Emirates Steel
- Emirates Authority for Standardization & Metrology (ESMA)
- Emirates Nature - WWF
- Industrial Development Bureau (IDB/DED)
- Abu Dhabi Quality and Conformity Council (QCC)
- Regulation and Supervision Bureau (RSB)
- Statistics Centre - Abu Dhabi (SCAD)

1.4.2 The Data Collection Process

The data collection was carried out with the support of our stakeholders. Figure 8 shows a scheme of the process. An important step was to define the data requirements for each sector and evaluate the available information from available statistics at the Emirate level. Based on this assessment, a data collection process was designed including the preparation of questionnaires and direct communication with stakeholders.

In the case of electricity production and oil and gas production, the required data was obtained directly from ADWEA and ADNOC, respectively, as it is described in the corresponding chapters. The data for the electricity sector was obtained from each power plant operator through the regular communication between EAD and each power plant operator. According to EAD permitting procedures, all major industries and power plants submit quarterly monitoring reports. These quarterly reports contain all the information related to the industry and the environment. For the power plants this report includes a specific chapter with the results of the Continuous Emission Monitoring (CEM) system installed in each major emission source.

For industrial processing, the needed input data to estimate emissions was obtained through questionnaires designed for this purpose. The questionnaires were originally designed by NILU, and thereafter we incorporated the feedback from the 'Permitting, Compliance and Enforcement Division' and the 'Air Quality, Noise and Climate Change Section' at EAD. Different questionnaires were prepared for different types of industries as it is explained in the chapter about industrial processing. They were distributed along with an introductory letter signed by EAD, explaining the purpose of this activity. The distribution and collection of questionnaires were centralised in a unique email addressed to facilitate the process (i.e. Air Emissions <air.emissions@ead.ae>).

The distribution of the questionnaires was supported by the organisation of a stakeholder workshop, which included a helpdesk, a session with the possibility of solving questions directly with NILU researchers and EAD experts. The industrial partners were invited to the workshop that was structured in such a way that introduced the overall activity, the purpose of the data collection and emission estimates and provided a practical guidance introducing the questionnaires and explaining every question in detail. The workshop was closed with a helpdesk session where the entities had the opportunity to ask specific questions about how to fill in the questionnaires.

The input data to estimate emissions from the remaining sectors (i.e. road transport, shipping, aviation, agriculture, livestock, and fugitive emissions) was obtained from different sources such as Statistics Centre Abu Dhabi (SCAD), Abu Dhabi Ports and the Department of Transport (DoT). Detailed information is provided in the corresponding chapters.

Consistency checks were performed where possible to ensure data quality; this included comparison of data received at different levels (i.e. summed entity level data vs. total Emirate data), as well as by independent cross-checking with other data sources.

Once the calculations were finalised and peer-reviewed by NILU and EAD experts, a final round of stakeholder engagement was organised to share with all the data providers the preliminary sector specific results. It included one-to-one meetings and feedback from the main data providers (DoT, ADNOC, Abu Dhabi Ports, SCAD, ADWEA, DED-IDB), a specific workshop with EAD subject matter experts, and a specific workshop with all the industry representatives in EAD HQ. Very positive feedback was received regarding the air emission inventory results and stakeholder engagement, which resulted in a satisfaction index of more than 89 % from the collected feedback forms.

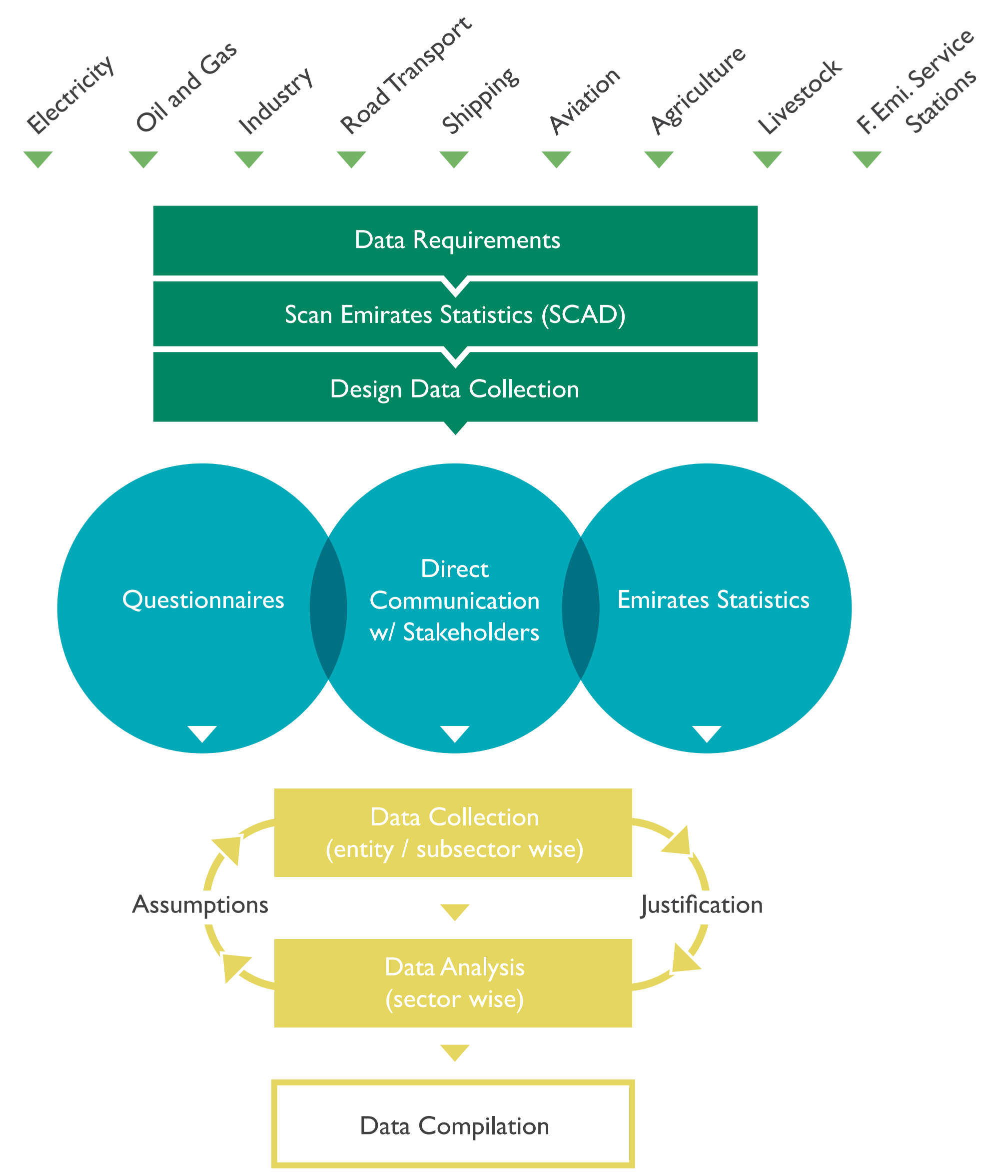


Figure 8: Flowchart representing the data collection process.

1.4.3 Emission Inventory Guidelines

EMEP/EEA Emission Inventory Guidebook (2016) was selected as a main guideline for emission estimates of most of the sectors, with the aim of estimating emissions at a level that involves a low uncertainty. EMEP/EEA (2016) recommends three tiers of increasing complexity, from tier 1 to tier 3. Tier 1 is based on statistical activity rate and default emissions factors, tier 2 uses more specific information (e.g. type of process or technology) and tier 3 involves greater level of disaggregation of activity data and emissions factors than tier 2. Higher tier level (tier 3) would imply lower uncertainty. In addition, for some industrial sub-sectors not directly covered by the EMEP/EEA guidelines (concrete), the US EPA AP42 (2012) guidelines were used.

Emissions from road transport traffic were estimated according to a bottom-up approach using the emission model based on the AirQUIS management system. The bottom-up emission model followed similar recommendations to the EMEP/EEA (2016) guidelines. Emissions were estimated at the road link based on information about the traffic expressed as average daily traffic (ADT), vehicle type and technology distribution, vehicle characteristics (e.g. year) and average annual driving distance. A detailed description of the method to estimate traffic emissions is presented in this report.

Emissions associated with shipping activities at the ports in Abu Dhabi Emirate were estimated following the recommendations from EMEP/EEA (2016) in combination with the method suggested by US EPA (2009).

1.4.4 Tools Used

The anthropogenic emission estimates were carried out in tailored spreadsheets (.xls) designed for this project with the exception of road transport emissions, which are estimated using a specialised modelling tool. The details of the traffic emission model and the input data are presented in the chapter "Road Transport Sector". The emission model has been used in a several scientific projects and to support Norwegian municipalities in the assessment of mitigation measures to reduce air pollution. The results from the traffic emission model have been used as input data in dispersion modelling with the subsequent validation by comparing with observations.

The preparation of files with geo-positioning information (e.g. shapefiles) in a geographical information system (GIS) has been done with ArcGIS software.

1.4.5 Missing Sectors

Some sectors were not originally prioritized in the development of the emission inventory due to their assumed low contribution to total emissions, and due to known difficulties to obtain input data. It is therefore recommendable to evaluate if any such sector may constitute a significant source of air pollutants. For instance, it is recommended in future cycles to investigate the off-road mobile combustion sources sector, which includes subsectors such as cargo handling equipment in airports and ports, tractors and other machinery used in the agriculture or industrial sector, construction sites, etc.

It is known that other energy sectors (residential, commercial, fishing, waste, etc.) produce air emissions. However the contribution of these sectors is expected to be negligible, based on the Greenhouse Gas Emission Inventory results, showing that these sectors contribute to approximately 0.5 % of the total GHG emissions (EAD 2016b).

Overall Inventory Results

2 Overall Inventory Results

Table 2 and Figure 9 show the overall emission inventory results, aggregated per sector. Oil and gas production and road transport are the main contributors to the emission of regulated pollutants. Oil and gas production contributes approximately 42 %, 95 %, 60 %, 32 % and 28 % of total NO_X, SO_2, NMVOC, $PM_{2.5}$ and PM_{10} emissions, respectively. Road transport provides 74 %, 34 %, 34 % and 17 % of total CO, NO_X, NMVOC and $PM_{2.5}$ emissions. It is noteworthy that the industry sector constitutes an important source of PM and CO, and livestock is a relatively important source of PM and NMVOC emissions.

Table 2: Results of the emission inventory for Abu Dhabi Emirate in 2015 (t/yr).
Note: n.a. means those emissions are not applicable for a sector.

	Emissions (t/yr)					
	NO_X	PM_{10}	$PM_{2.5}$	SO_2	CO	NMVOC
Electricity	13,479	173	172	1,586	7,920	1,213
Oil and Gas	43,996	2,793	2,793	353,998	22,093	61,663
Industry	8,315	4,429	3,645	13,645	122,934	1,859
Road Transport	36,017	1,464	1,464	399	441,056	34,878
Shipping	1,650	192	192	949	216	125
Aviation	2,529	15	15	156	593	19
Agriculture	n.a.	96	4	n.a.	n.a	53
Livestock	n.a.	727	319	n.a.	n.a.	2,255
Fugitive Emissions at Service Stations	n.a.	n.a.	n.a.	n.a.	n.a.	193
TOTAL	105,986	9,888	8,604	370,732	594,813	102,258

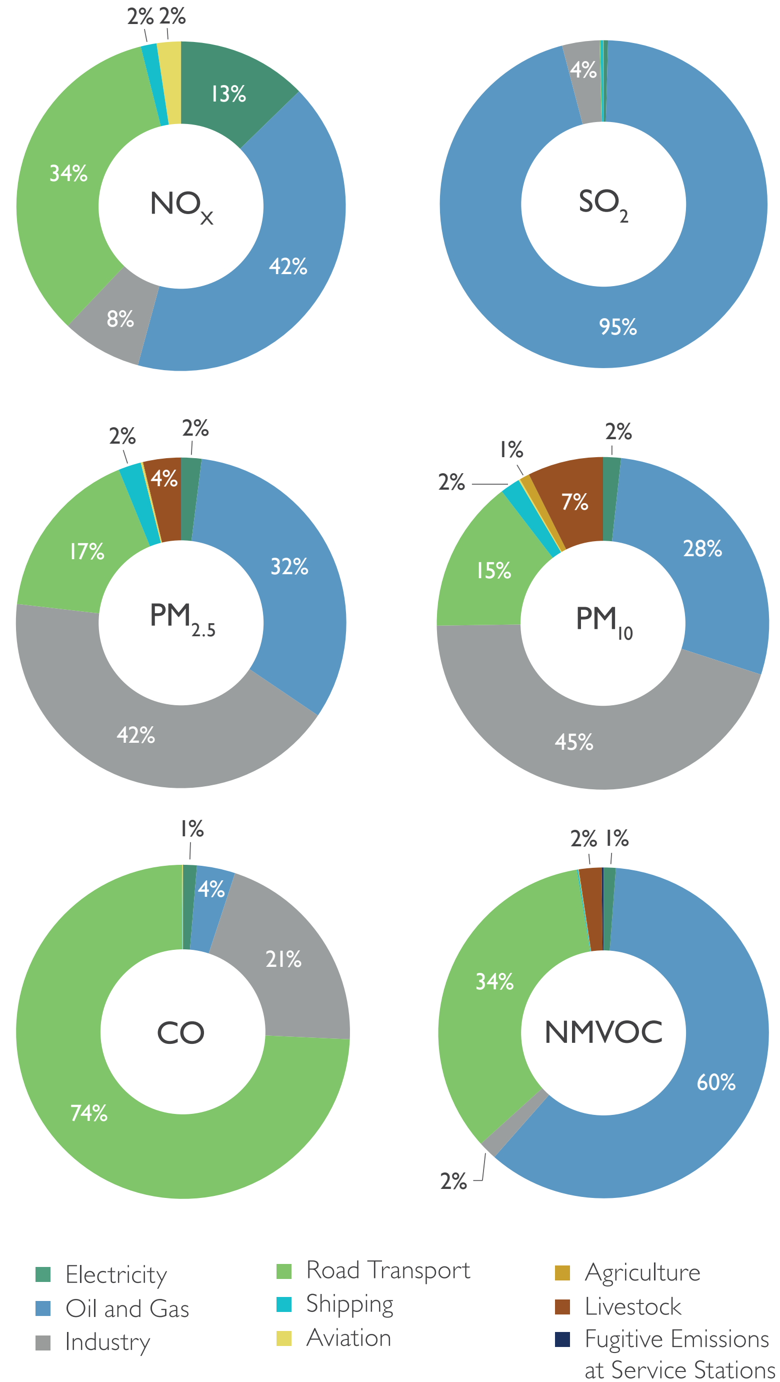


Figure 9: Sectoral distribution of NO_X, PM_{10}, $PM_{2.5}$, SO_2, CO and NMVOC emissions in Abu Dhabi Emirate in 2015. Note: Contributions <1 % are not labelled on the figure, for clarity.

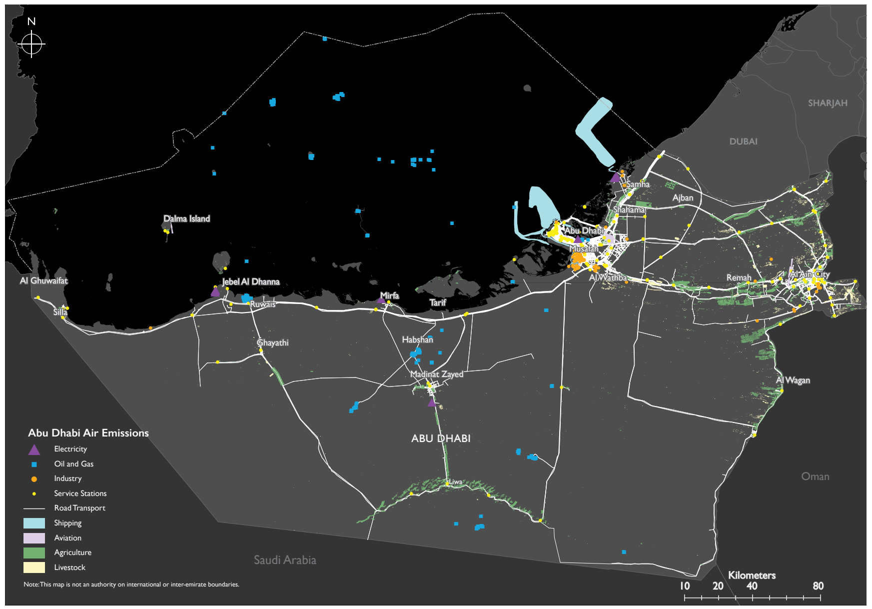


Figure 10: Location of the emission sources by sector in Abu Dhabi Emirate.

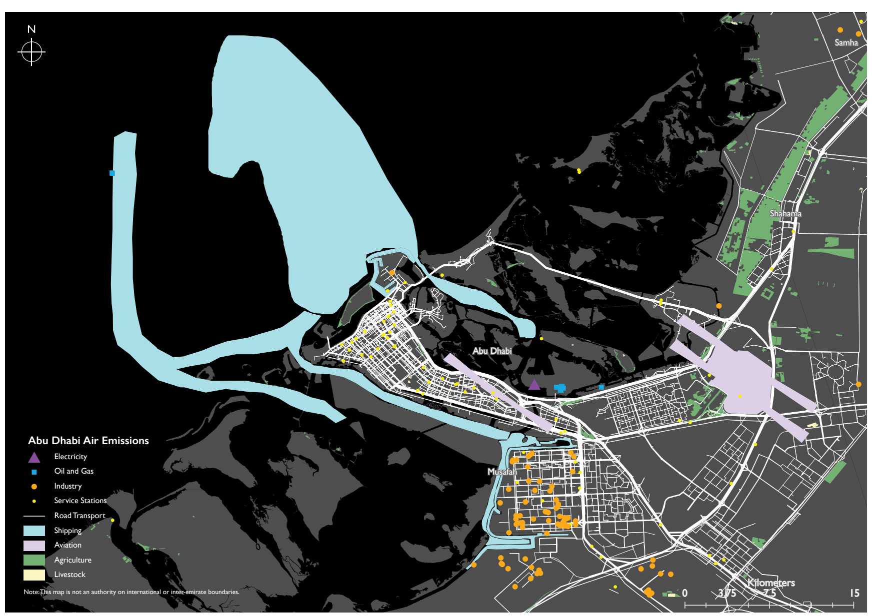


Figure 11: Location of the emission sources by sector in Abu Dhabi Emirate (zoom in Abu Dhabi Island).

All the available data has been collected, validated and stored in a standardised geographic database. Detailed maps have been created to represent the emission sources by sector, such as the maps on the left (See Figure 2 and Figure 3 for higher resolution maps). The electricity power plants are located in key areas along the emirate in order to provide electricity and water desalination to the different regions. Oil and Gas activities are distributed onshore and offshore in strategic locations, mainly in the Al Dhafra Region. The industrial sector is diversified across the emirate, though many of the key industries are located in the big industrial hubs: Mussafah; Industrial City of Abu Dhabi (ICAD); Khalifa Industrial Zone (KIZAD); and Al Ain Industrial City (AAIC). Road transport is distributed in all the regions, with a higher density in Abu Dhabi Island and the main highways that connect the emirate. Shipping and aviation emissions are located in the main ports and airports. Livestock and agriculture activities are mostly found in the Al Ain Region, and petrol stations are spread along the road network.

In order to provide a clear picture of the emissions in each area, high definition emission maps have been developed as part of this project (Figure 12 to Figure 17). These maps show the annual amount of emissions in a high resolution cell of 1 by 1 km, following international best practices.

The main conclusions about the location and intensity of the sources for each pollutant are:

- Nitrogen Oxides (NO_X): most of the emissions are located along the transportation areas (road network, ports and airports zones); in the big metal industries and cement production industries; in the oil and gas areas; and in the electricity and water desalination plants.
- Sulphur Dioxide (SO_2): the largest amount of emissions are located in the offshore and onshore oil and gas activities; in the key aluminium industries and in the main ports area.
- Carbon Monoxide (CO): the CO emissions are mostly emitted near the main road network; and in the industrial areas.
- Non-methane Volatile Organic Compounds (NMVOC): are emitted in the oil and gas areas and near the main roads.
- Particulate Matter (PM_{10} and $PM_{2.5}$): the main emission can be found in the industrial areas; near the areas with high road traffic; and in the offshore oil and gas activities.

These conclusions show the complexity of the air emissions in Abu Dhabi Emirate, which requires a cross-sectoral approach, joined efforts and close collaboration between government entities and the private sector. A collaboration that has been highly successful in the development of this project, with a wide range of stakeholders involved from all the relevant sectors.

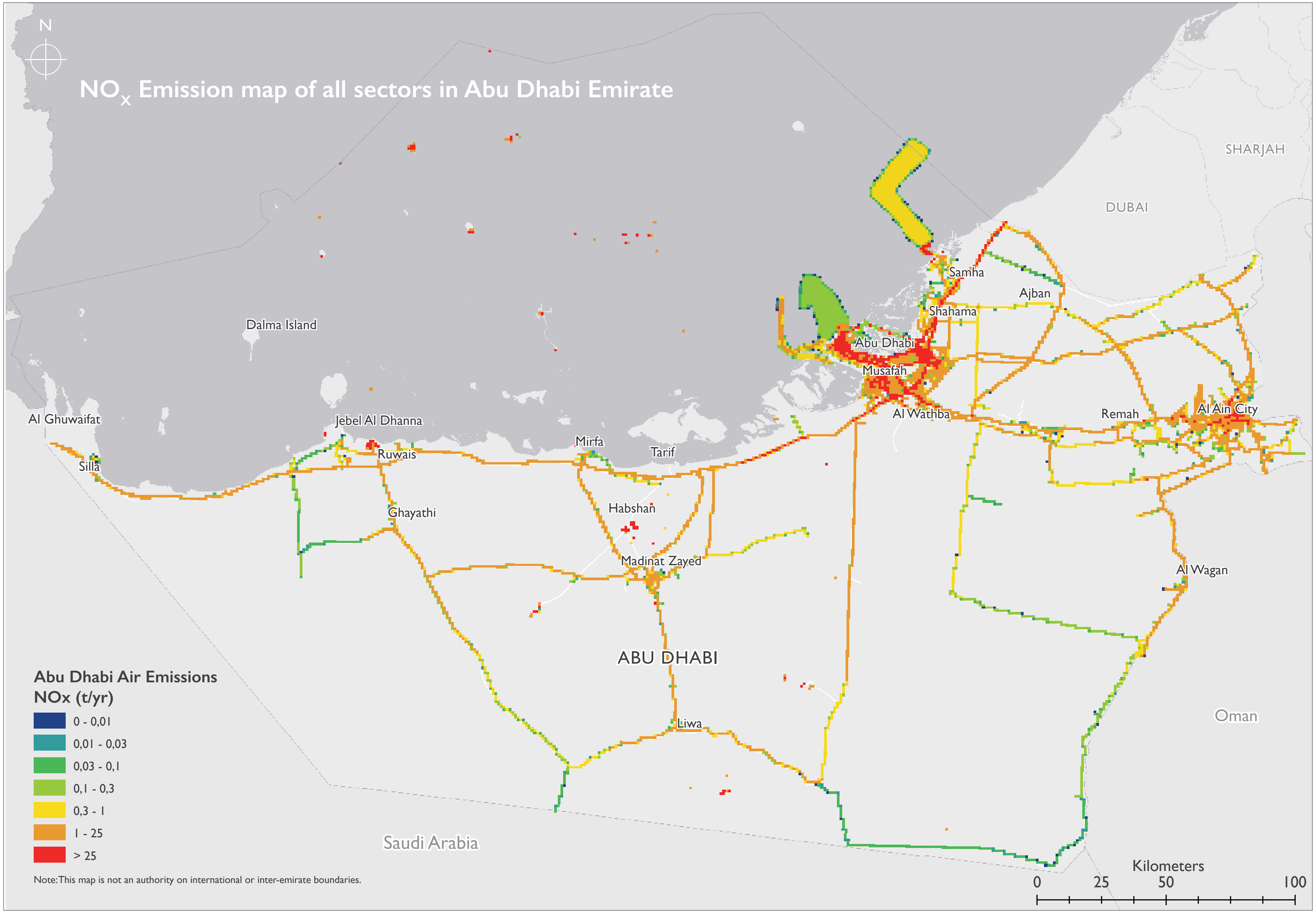


Figure 12: NO_x Emission map of all sectors in Abu Dhabi Emirate

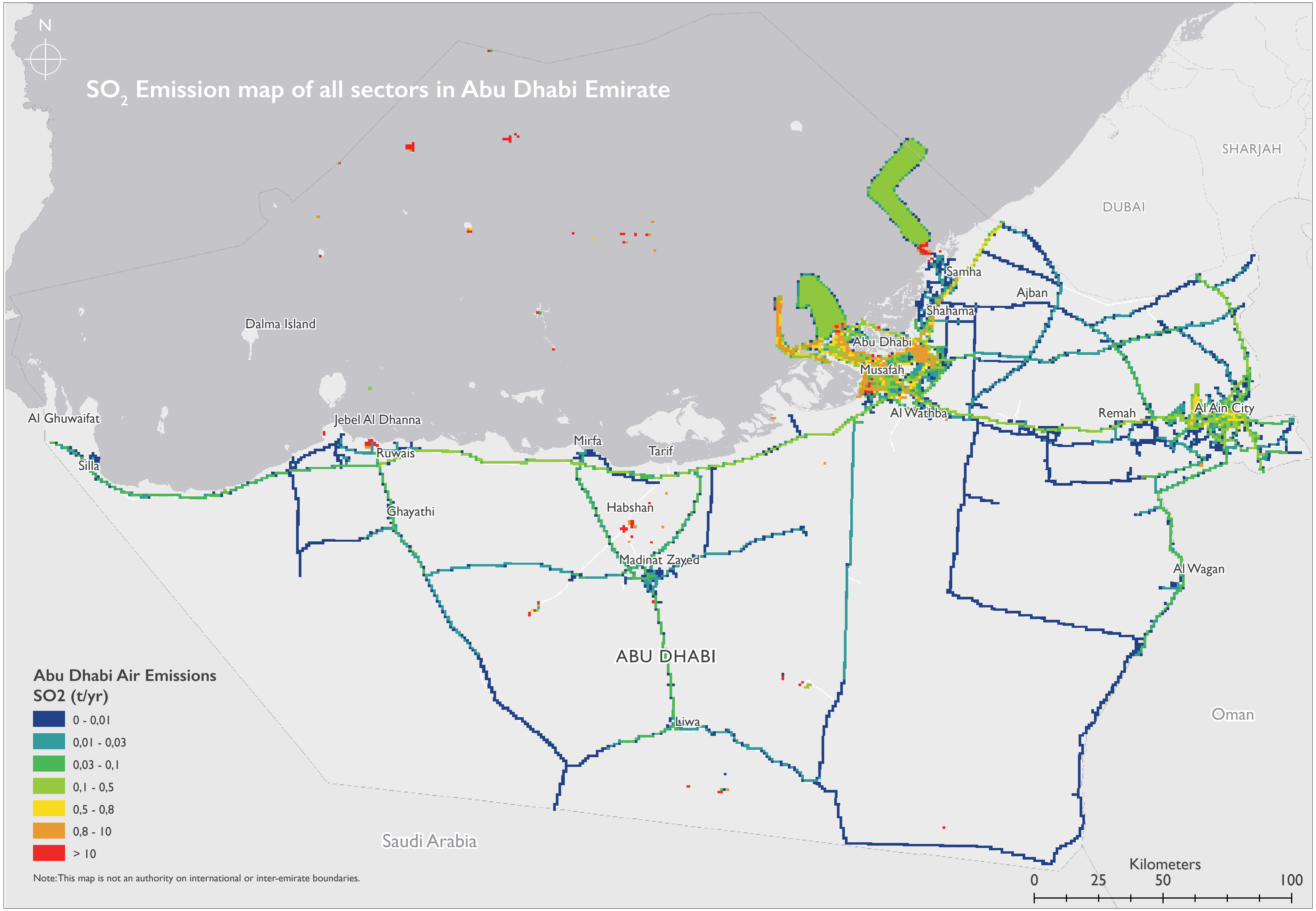


Figure 13: SO_2 Emission map of all sectors in Abu Dhabi Emirate

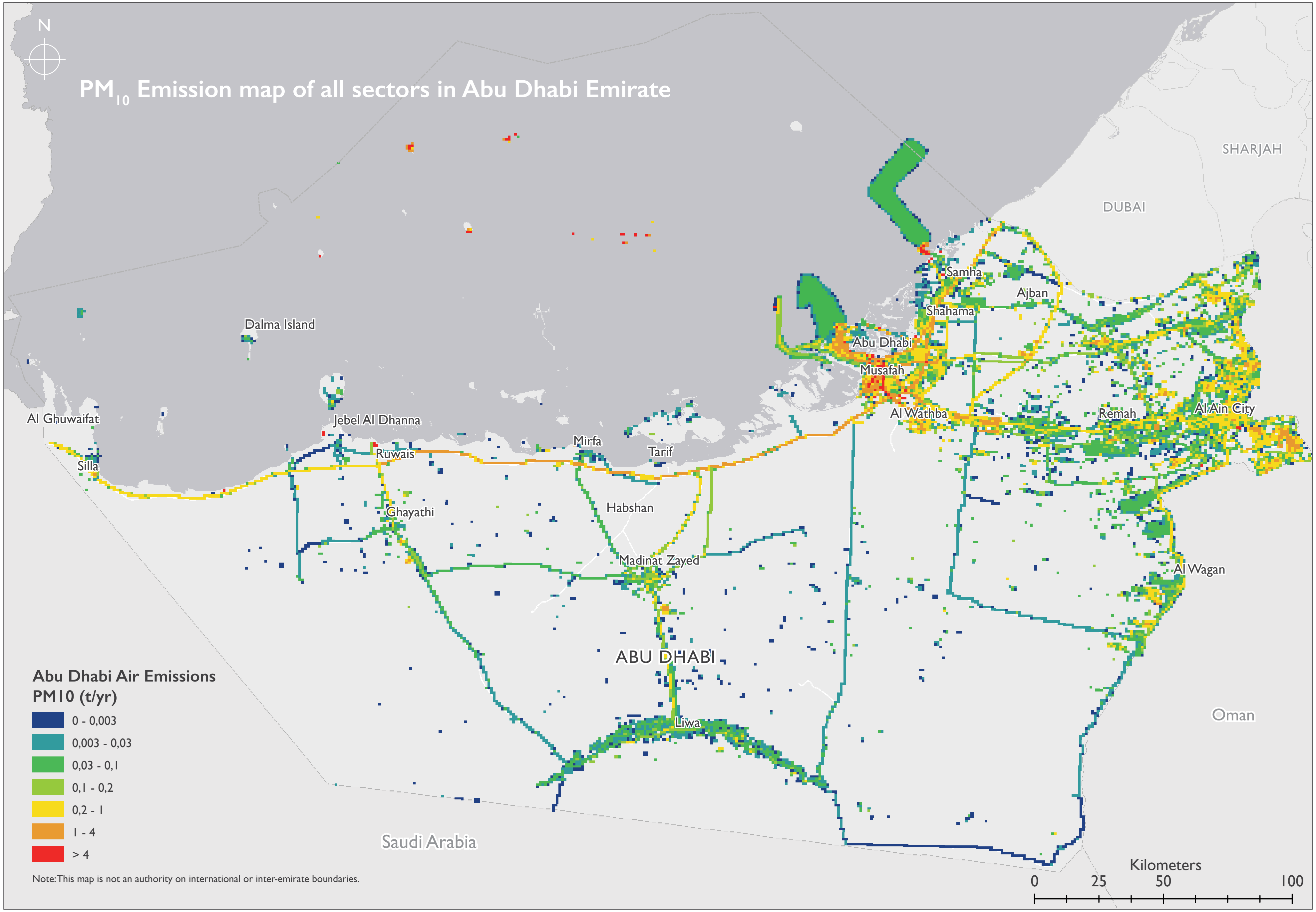


Figure 14: PM_{10} Emission map of all sectors in Abu Dhabi Emirate

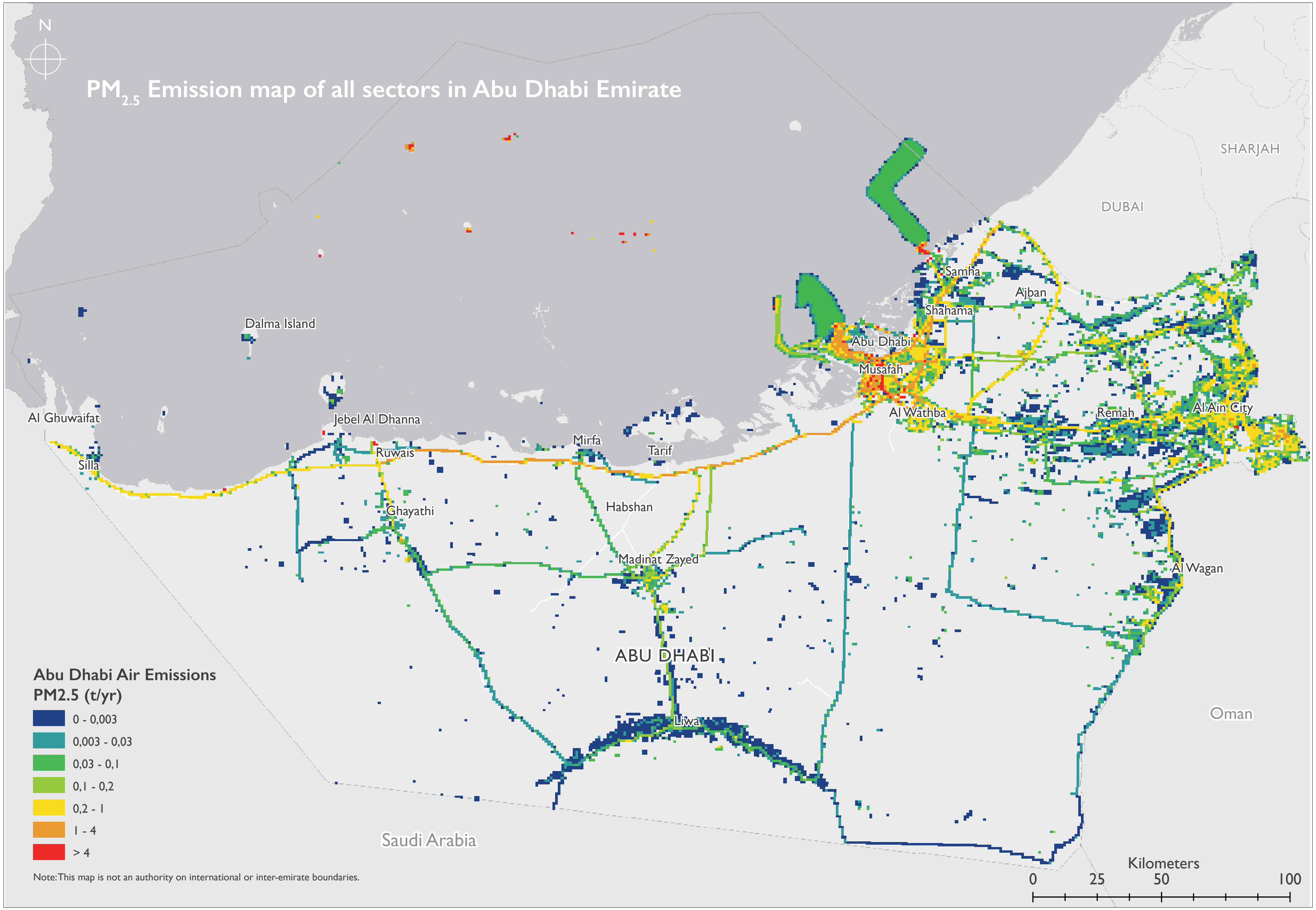


Figure 15: $PM_{2.5}$ Emission map of all sectors in Abu Dhabi Emirate

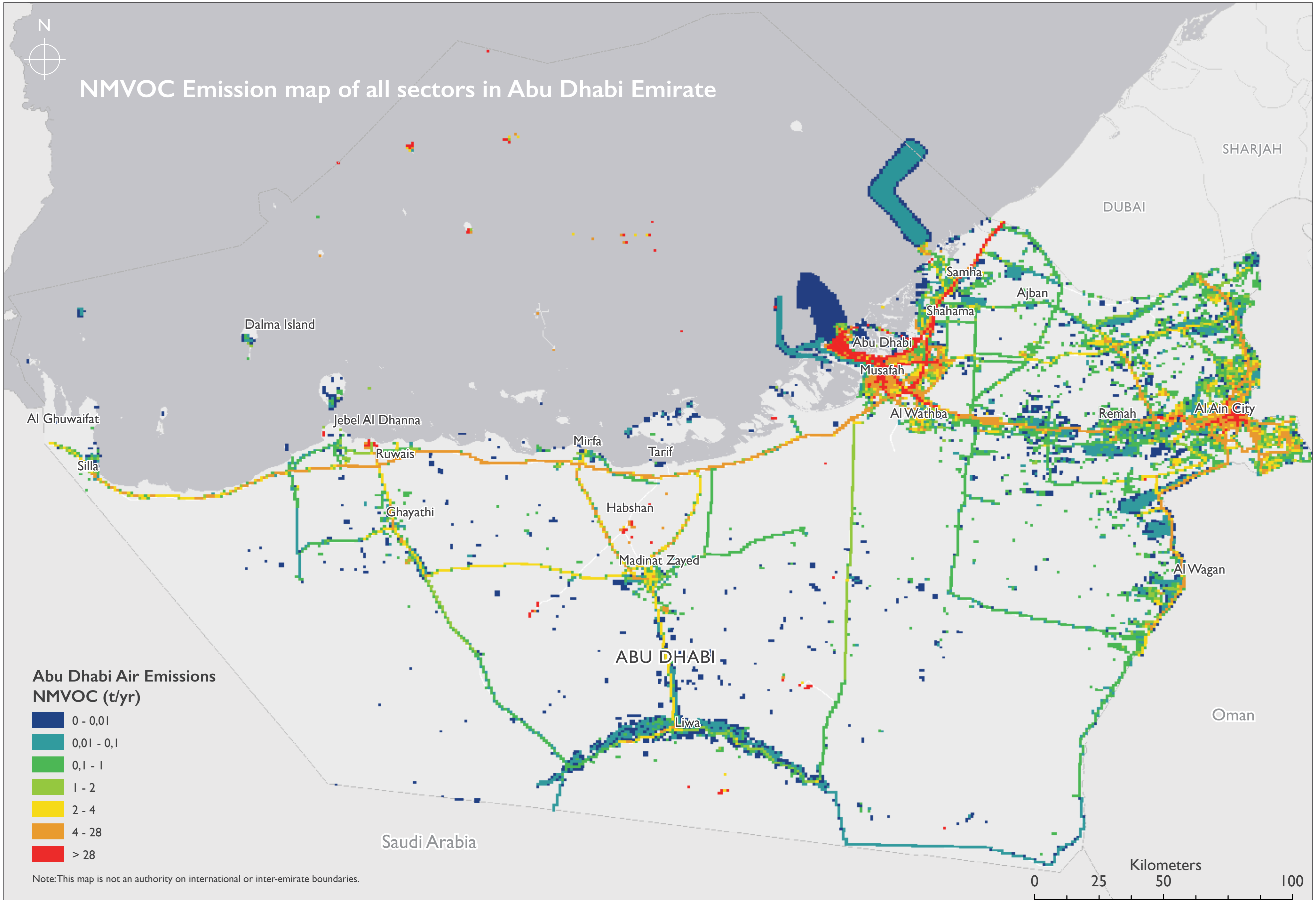


Figure 16: NMVOC Emission map of all sectors in Abu Dhabi Emirate

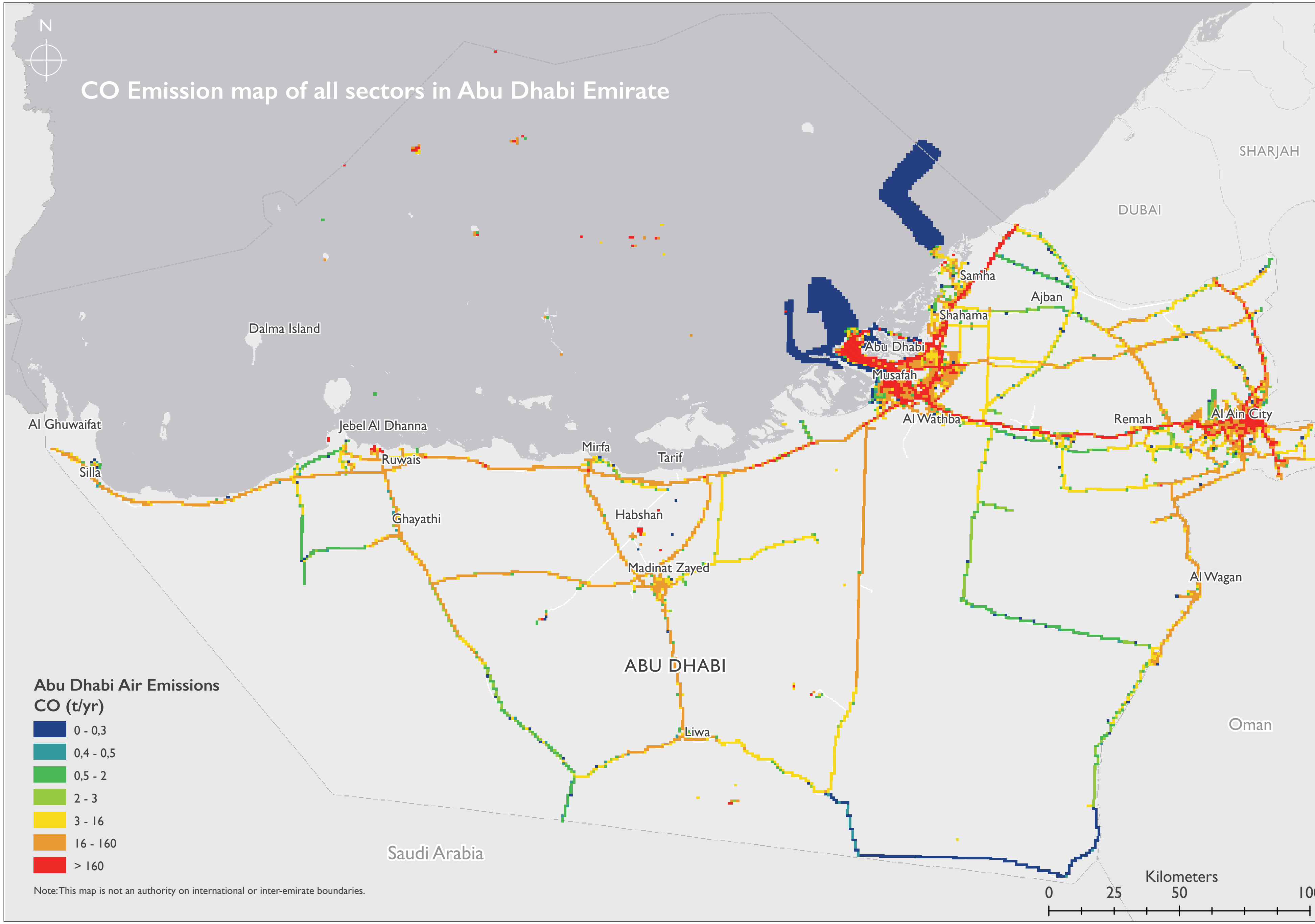


Figure 17: CO Emission map of all sectors in Abu Dhabi Emirate

Electricity

3 Electricity

3.1 Method to Estimate Electricity Production Emissions

In the Abu Dhabi Emirate, electricity is produced by the Abu Dhabi Water & Electricity Authority (ADWEA), and is generally combined with the production of desalinated water. Some electricity may also be transferred to the grid from other industrial facilities, e.g. Abu Dhabi Oil Refining Company (TAKREER) and Emirates Global Aluminium (EGA). ADWEA operators include Arabian Power Company (APC, Umm Al Nar plant), Gulf Total Tractebel Power Company (GTTPC), Emirates CMS Power Company (ECPC), Taweelah Asia Power Company (TAPCO), Shuweihat CMS International Power Company (SCIPCO), Ruwais Power Company (RPC), Shuweihat Asia O & M Company (SAPCO), Al Mirfa Power Company (AMPC), and Shams Power Company PSJC A1.

The general technology used is stationary combustion in combined heat and power (CHP) plants, although other technology (e.g. solar) is also used. Generation capacity of plants operating in the year 2015 is given in Table 3. According to ADWEC (2015), the total electricity production for the year 2015, excluding facilities outside the Abu Dhabi Emirate (Emirates SembCorp Water & Power Company and Fujairah Asia Power Company), was 66,627 GWh. Similarly, desalinated water production within the Abu Dhabi Emirate was 205,817 MIG (ADWEC, 2015).

For NO_X, CO and SO_2, emission data (in t/yr) was obtained from each power plant operator by regular communication to EAD. According to EAD permitting procedures, all major industries and power plants submit quarterly monitoring reports. These quarterly reports contain all the information related to the industry and the environment. For the power plants this report includes a specific chapter with the results of the Continuous Emission Monitoring (CEM) system (or grab data) installed in each major emission source. Since the annual emission data represents either Continuous Emission Measurements (CEM) or grab data, it is therefore of Tier 3 standard. Due to lack of other data, emissions for Mirfa Power Plant were sourced from SCAD (2016).

NMVOC, $PM_{2.5}$ and PM_{10} emissions were calculated according to the guidelines from EMEP/EEA (2016). A Tier 2 emission factor approach was taken, based on the quantity of natural gas, crude oil and gas oil combusted per station per year (data from ADWEC, 2016b) and the emission factor for that fuel type and combustion technology.

Table 3: Plant generation capacity in the Abu Dhabi Emirate for the year 2015 (ADWEC, 2015, ADWEC, 2016a and Abengoa Solar, 2014). Power and water generation capacities listed do not include new plant facilities, which were not active as of the year 2015.

Power Plant Name	Project owner/ operator	Total power generation capacity in 2015 (MW)	Total water generation capacity in 2015 (MGD)
Umm Al Nar Plant	Arabian Power Company (APC)	2,430	145
Taweelah A1 Plant	Gulf Total Tractebel Power Company (GTTPC)	1,671	84
Taweelah A2 Plant	Emirates CMS Power Company (ECPC)	760	51
Taweelah B Plant	Taweelah Asia Power Company (TAPCO)	2,220	162
Shuweihat S1 IWPP	Shuweihat CMS International Power Company (SCIPCO)	1,615	101
Shuweihat S2 IWPP	Ruwais Power Company (RPC)	1,627	101
Shuweihat S3 IPP	Shuweihat Asia O & M Company (SAPCO)	1,647	0
Al Mirfa, Al Ain and Madinat Zayed Power stations	Al Mirfa Power Company (AMPC)	551	39
Shams 1	Shams Power Company PSJC	50	0

The same approach was taken for SO_2 emissions from the Taweelah A1 plant, in the absence of reported tonnes per year emission data. Emission factors used in our study are shown in Table 4, sourced from the EMEP/EEA (2016) guidebook. From plant descriptions, it was assumed that most natural gas was combusted in gas turbines, and most crude oil and gas oil was combusted in stationary (reciprocating) engines. 99.84 % of fuel combusted was natural gas. Estimating natural gas combustion emissions (for NMVOC, $PM_{2.5}$ and PM_{10}) using a Tier 2 rather than Tier 1 approach means that due to differences in emission factor applied, resulting values are between 22 % and 62 % lower.

The approach is shown in Equation 2, where Epollutant is the quantity of pollutant emitted during the year 2015, $\sum_{technologies}$ is the total for all technologies and fuel combusted, $AR_{productiontechnology}$ is the activity data for fuel combusted for each technology, and $EF_{technologypollutant}$ is the emission factor for that specific fuel, technology and pollutant.

$$Epollutant = \sum_{technologies} AR_{productiontechnology} \times EF_{technologypollutant} \quad \textit{Equation 2}$$

Total natural gas combusted for the year was 731 PJ, crude oil combusted was 1,043 TJ, and gas oil was 143 TJ. This fuel only relates to that used for electricity production and water desalination, and not other facility operational activities.

Table 4: Emission factors (g/GJ) for NMVOC, $PM_{2.5}$ and PM_{10} emissions from fuel combustion for electricity production (EEA/EMEP, 2016). Note: * indicates that the emission factor was for total suspended particles (TSP), and it was assumed that $TSP=PM_{10}=PM_{2.5}$.

	Emission factors (g/GJ)			
	EF_{NMVOC}	$EF_{PM2.5}$	EF_{PM10}	EF_{SO2}
Gas turbines (natural gas)	1.6	0.2*	0.2*	0.281
Stationary reciprocating engines (crude oil and gas oil)	37.1	21.7	22.4	46.5

3.2 Emissions from Electricity Production

Emissions from electricity production for the year 2015 are shown in Table 5. In addition, the contribution from each facility to the total emissions is shown in Figure 7. The highest emissions of NO_X are derived from APC (31 %), SCIPCO (19 %) and GTTPC (16 %), and the highest emissions of SO_2 are derived from APC (25 %), SAPCO (25 %) and TAPCO (18 %). This largely reflects which facilities are producing the most electricity and water, shown in Figure 8, although differences may also relate to variations in technology or fuel type/composition between the facilities. Variation in combustion technology is also indicated by a varying NO_X:CO emission ratio amongst the facilities.

Using an average fuel allocation factor to water desalination of 31 % (EAD, 2016b), average NO_X emission indicators for the plants are 0.14 t NO_X/GWh, and 0.02 t NO_X/MIG for electricity production and water desalination, respectively.

Table 5: Emissions from electricity production (t/yr) in Abu Dhabi Emirate in 2015, distributed by facility.
Note: All values in the table are rounded to the nearest integer.

	Emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
APC	253	32	32	4,195	986	400
GTTPC	173	22	22	2,215	2,135	32
ECPC	86	11	11	478	239	79
TAPCO	270	52	52	1,586	891	292
AMPC	24	3	3	270	0	14
SCIPCO	158	20	20	2,565	1,484	218
RPC	155	20	20	1,244	1,983	127
SAPCO	93	12	12	898	175	404
SHAMS	1	0	0	27	27	22
TOTAL	1,213	172	173	13,479	7,920	1,586

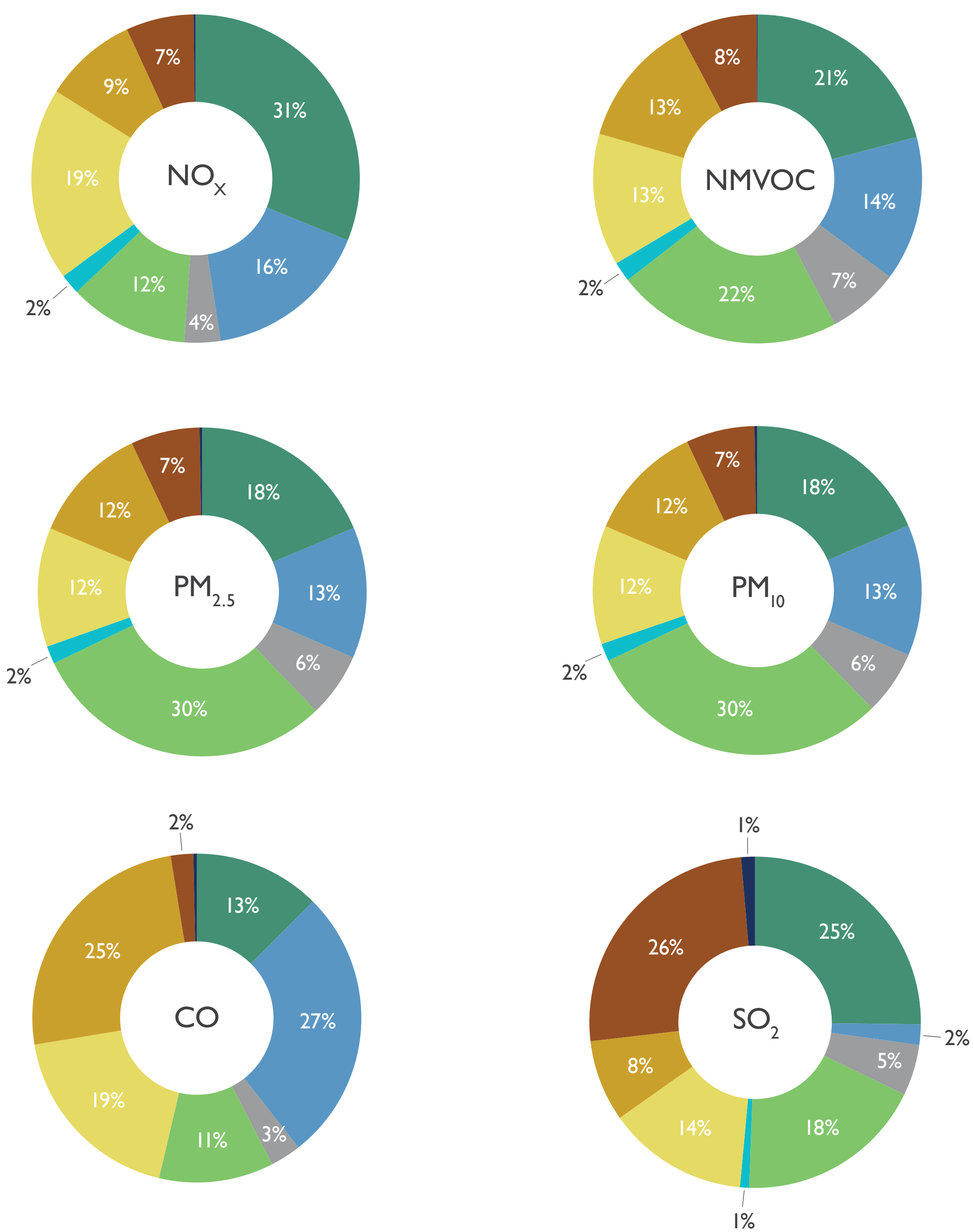


Figure 18: NO_X, SO_2, CO, NMVOC, $PM_{2.5}$ and PM_{10} emissions from electricity production in Abu Dhabi Emirate in 2015, distributed by ADWEA facilities. Facilities contributing <1 % are not labelled on the figures for clarity.

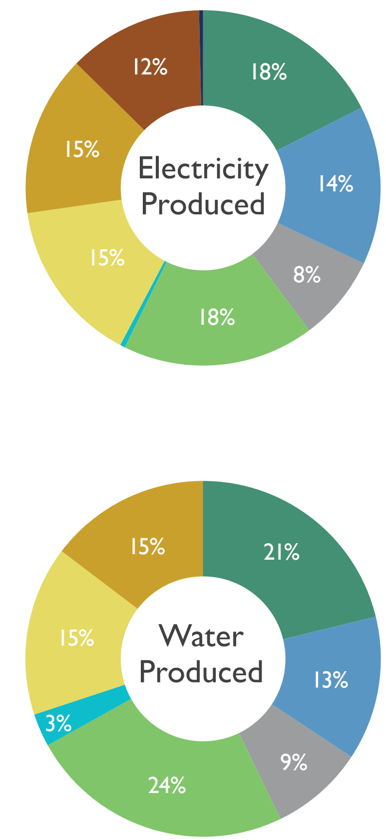
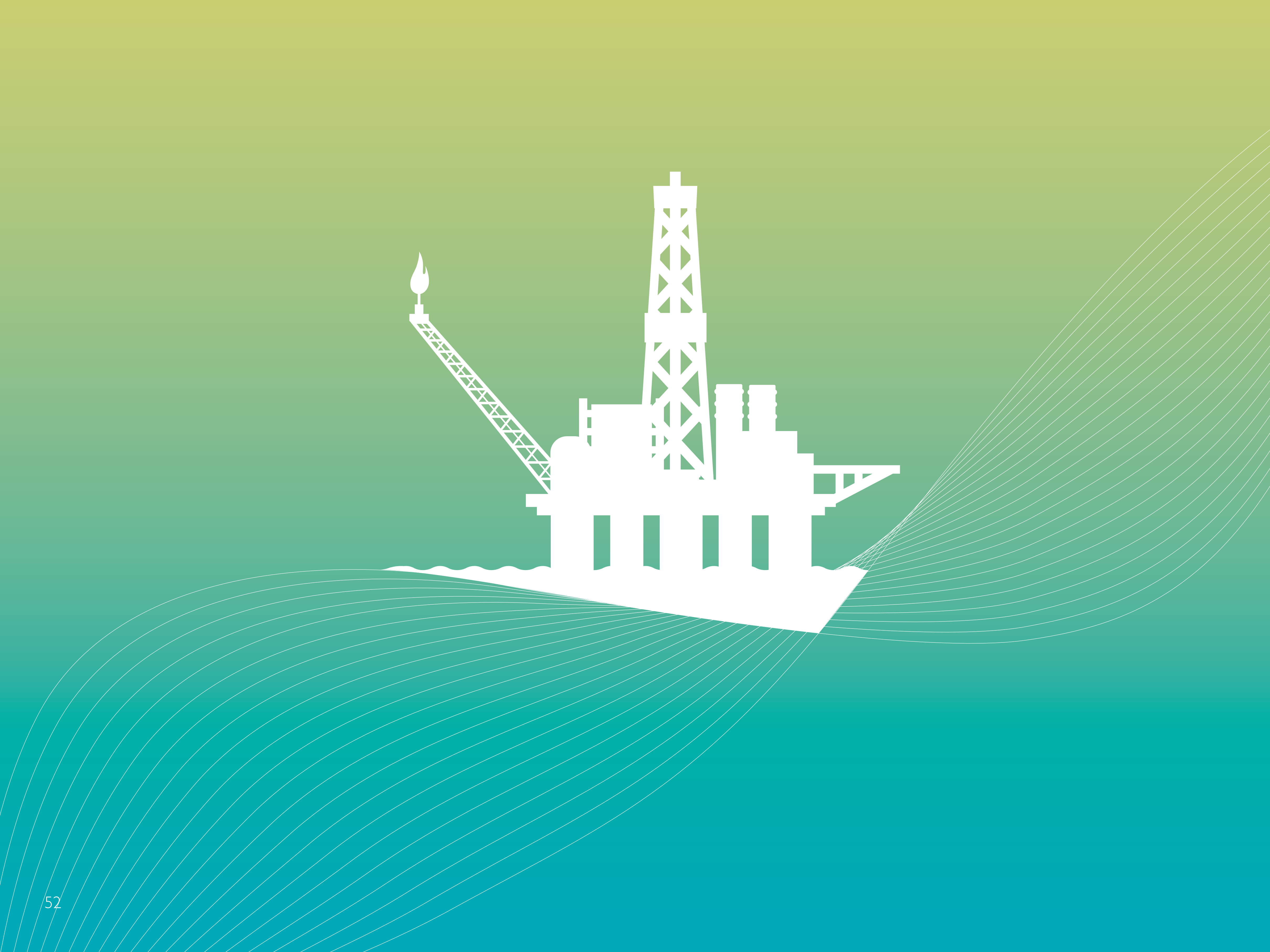


Figure 19: Electricity and desalinated water produced in Abu Dhabi Emirate in 2015, distributed by ADWEA facilities (ADWEC, 2015). Facilities contributing <1 % are not labelled on the figures for clarity



Oil and Gas

4 Oil and Gas

4.1 Method to estimate Oil and Gas Production Emissions

Oil and gas, as well as refined petroleum products, are produced in the Abu Dhabi Emirate by the Abu Dhabi National Oil Company (ADNOC). ADNOC entities are classified by activity as exploration and production, processing and refining, or marketing and distribution. Regarding the year 2015, exploration and production entities included Abu Dhabi Company for Onshore Petroleum Operations Ltd (ADCO), Abu Dhabi Marine Operating Company (ADMA-OPCO), Zakum Development Company (ZADCO), National Drilling Company (NDC), Abu Dhabi Oil Company (ADOC), Bunduq, and Total Abu Al Bukhoosh (Total ABK). Processing and refining entities included Al Hosn, Abu Dhabi Gas Liquefaction Company Limited (ADGAS), ADNOC Linde Industrial Gases Company Limited (ELIXER), Abu Dhabi Gas Industries Limited (GASCO), Abu Dhabi Oil Refining Company (TAKREER), Abu Dhabi Polymers Company Limited (BOROUGE) and Ruwais Fertilizer Industries (FERTIL). Emissions from marketing & distribution facilities were not included in this section to avoid double counting with other sectors such as transport. Production and exports of petrochemical products reached 6,124,940 metric tonnes in 2015 (SCAD, 2016). Emissions arise from oil and gas activities both by stationary combustion and as fugitive emissions.

Emission data was submitted by ADNOC direct to EAD on both an aggregated and disaggregated facility level, which was assumed to be of Tier 3 standard. Aggregated data was given at a facility level, whereas disaggregated data was given per stack at each facility. Units were in tonne per year or in gram per second. Where a unit of g/s existed with stack data, data was converted to t/yr assuming a full operating time of 8,760 working hours per year. Since there were some differences between the total values of emissions in the aggregated and disaggregated files (aggregated facility level data included all emissions including venting and fugitive emissions while disaggregated facility level accounts only included emissions from stacks), disaggregated emissions were renormalized using the totals from the aggregated file. Only the aggregated facility data was received for two facilities. Although the reported emissions give a snap-shot of ADNOC emissions for the year 2015, they do not necessarily represent regular operation. For example, it was advised that emissions from Al Hosn were not typical for the year 2015, due to start-up and commissioning of the Shah gas plant (during which time higher flaring levels were recorded).

Not all criteria pollutants were reported by ADNOC. In general, volatile organic compounds (VOC), CO, NO_X, and $SO_2/_x$ were reported, whilst $PM_{2.5}$ and PM_{10} were generally not given. Where data was not reported, data gaps exist since these could not be filled with emission factor calculations due to a lack of associated activity data. The exception was for three facilities where no PM emission data was reported for the year 2015, but was reported during the last round of the inventory. In this case, PM emissions were scaled up to 2015 based on the ratio of NO_X in 2009 and in 2015. Given a lack of data, PM emissions were assumed to equal PM_{10}, which was assumed equal to $PM_{2.5}$. Since a larger quantity of CH4 was reported separately, VOC was assumed to equal NMVOC.

4.2 Emissions from Oil and Gas Production

Emissions from oil and gas production for the year 2015 are shown in Table 6. In addition, the distribution of emissions by ADNOC activity are given in Figure 9. The highest emissions of NO_X, SO_X and CO derived from processing and refining activities (75 %, 85 % and 78 %, respectively). The highest emissions of NMVOC derived from exploration and production (85 % of NMVOC total). Since $PM_{2.5}$, PM_{10} were not consistently reported across all ADNOC facilities, these emissions were not compared in this manner.

Table 6: Emissions from oil and gas production (t/yr) in Abu Dhabi Emirate in 2015, distributed by ADNOC activity (exploration and production, and processing and refining). Note: All values in the table are rounded to the nearest integer. * indicates that VOC was reported by ADNOC, and not NMVOC.

	Emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
Exploration and production	52,295*	1,929	1,929	10,870	4,887	52,977
Processing and refining	9,367*	864	864	33,126	17,206	301,021
TOTAL	61,663*	2,793	2,793	43,996	22,093	353,998

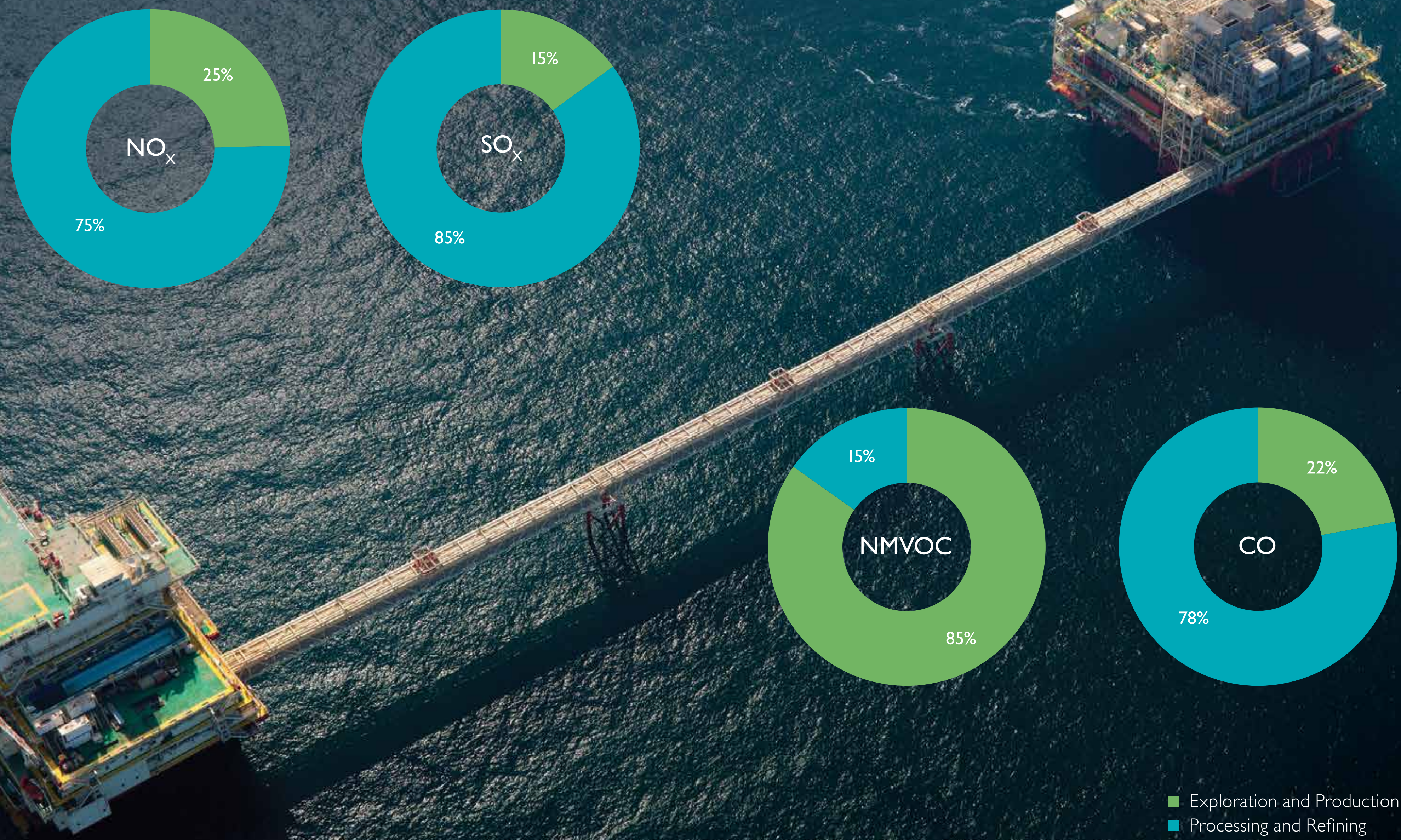


Figure 20: NO$_X$, SO$_X$, NMVOC and CO emissions from oil and gas production in Abu Dhabi Emirate in 2015, distributed by ADNOC activity (exploration and production, and processing and refining).

Industry Sector

5 Industry Sector

A bottom-up analysis was carried out to estimate industrial processing emissions within the Abu Dhabi Emirate. This sector includes emissions from any processes, as well as any fuel combusted, from industrial processing. Notable industrial sub-sectors in the Abu Dhabi Emirate that release large amounts of emissions include aluminium, iron and steel, asphalt, cement and concrete.

5.1 General Method to Estimate Industry Emissions

An initial assessment was carried out to identify relevant industrial sub-sectors for prioritisation in Abu Dhabi Emirate. The selection was carried out based on i) the EAD sector assessment reports; ii) the risk assessments performed by EAD using the Risk Characterisation and Hazard Evaluation System (RiCHES), and iii) the industries that reported in the previous emission inventory. Based on this, lists of entities were identified according to the following sub-sectors:

- Asphalt
- Cement and concrete
- Iron and steel
- Aluminium Production
- Chemical Manufacturing
  – Fertilisers and Nitrogen Compounds - Organic
  – Fiberglass-reinforced Plastics Products Manufacturing
  – Paints, Inks and Varnishes
- Plastic Products
- Food Production
- Paper and Pulp

The needed input data to estimate industry emissions was obtained through questionnaires distributed to each individual facility. A specific database was created with the details stored in the permitting application and in the inspection database, which included the most updated contact details for each entity. The distribution and collection of the questionnaires was centralized in a unique email address to facilitate the process (i.e. Air Emissions <air.emissions@ead.ae>).

Specific questionnaires were designed for different types of industries taking into consideration the specific processes and the data needed for the emission calculation. Questionnaires were divided into 1) Asphalt, 2) Cement (and concrete), 3) Iron and steel, and 4) General industry categories. Data was primarily collected regarding facility location, production and consumption of raw materials and fuels and emission mitigation technology.

Questionnaires were subsequently distributed to relevant entities requesting collaboration on data collection, following a stakeholder meeting where the aim, methods and data needs were explained. The distribution of the questionnaires was supported by the organisation of a stakeholder workshop, with more than 100 attendees. The workshop included a helpdesk, a session with the possibility of solving questions directly with NILU researchers and EAD experts. The industrial partners were invited to the workshop that was structured in such a way that introduced the overall activity, the purpose of the data collection and emission estimates, and provided a practical guidance introducing the questionnaires and explaining every question in detail. The workshop was closed with a helpdesk session where the entities had the opportunity to ask specific questions about how to fill in the questionnaires.

A high effort was put into stakeholder engagement, in order to encourage completed questionnaire submission from entities. The emissions calculated for the Industrial Processing sector are incomplete for the Emirate, due to the 'bottom-up' approach used, however it is considered that the results represent the majority of emissions.

Although it is difficult to estimate the relative completeness of the resulting calculated emissions, an approach may be taken by comparing the quantity of fuel combusted in the industrial sector in the Emirate according to SCAD ('top down' approach) with the total quantity of fuel reported by facilities in the 'bottom-up' approach taken here.

Results of the analysis (Figure 13) showed that 28 % more gaseous fuel, and 87 % less liquid fuel, was reported in questionnaires than by SCAD, for the combined electricity and industry sectors. The total fuel (GJ), including gaseous plus liquid fuel, was 25 % higher from questionnaires than reported by SCAD. This shows that a), the feedback from the questionnaires within this project covered the key emitting industries (as indicated by total GJ fuel combustion), b), there may be some over-reporting of fuel consumption on returned questionnaires, and c) there is a trend that the key emitting industries utilise natural gas rather than liquid fuel. Fuel over-reporting may be due to erroneous reporting of fuel used for transport purposes attributable partly to differences in understanding the method. Small differences may also arise due to variations in unit conversion method, performed in this report, or by SCAD.

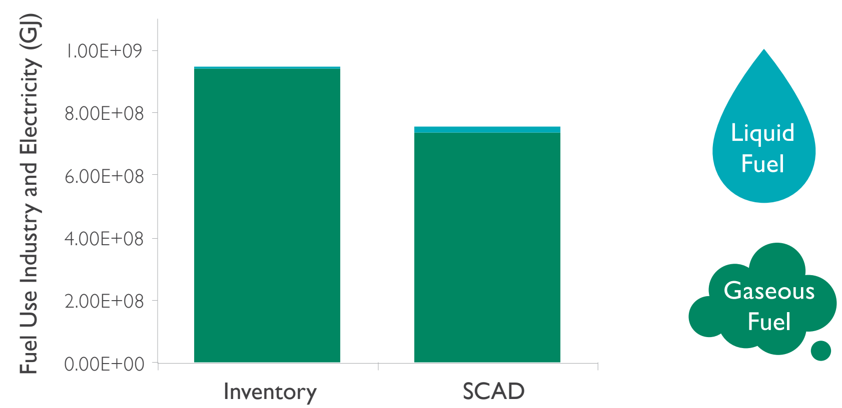


Figure 21: Total fuel consumption reported in electricity and industry sectors in this inventory, or by SCAD.

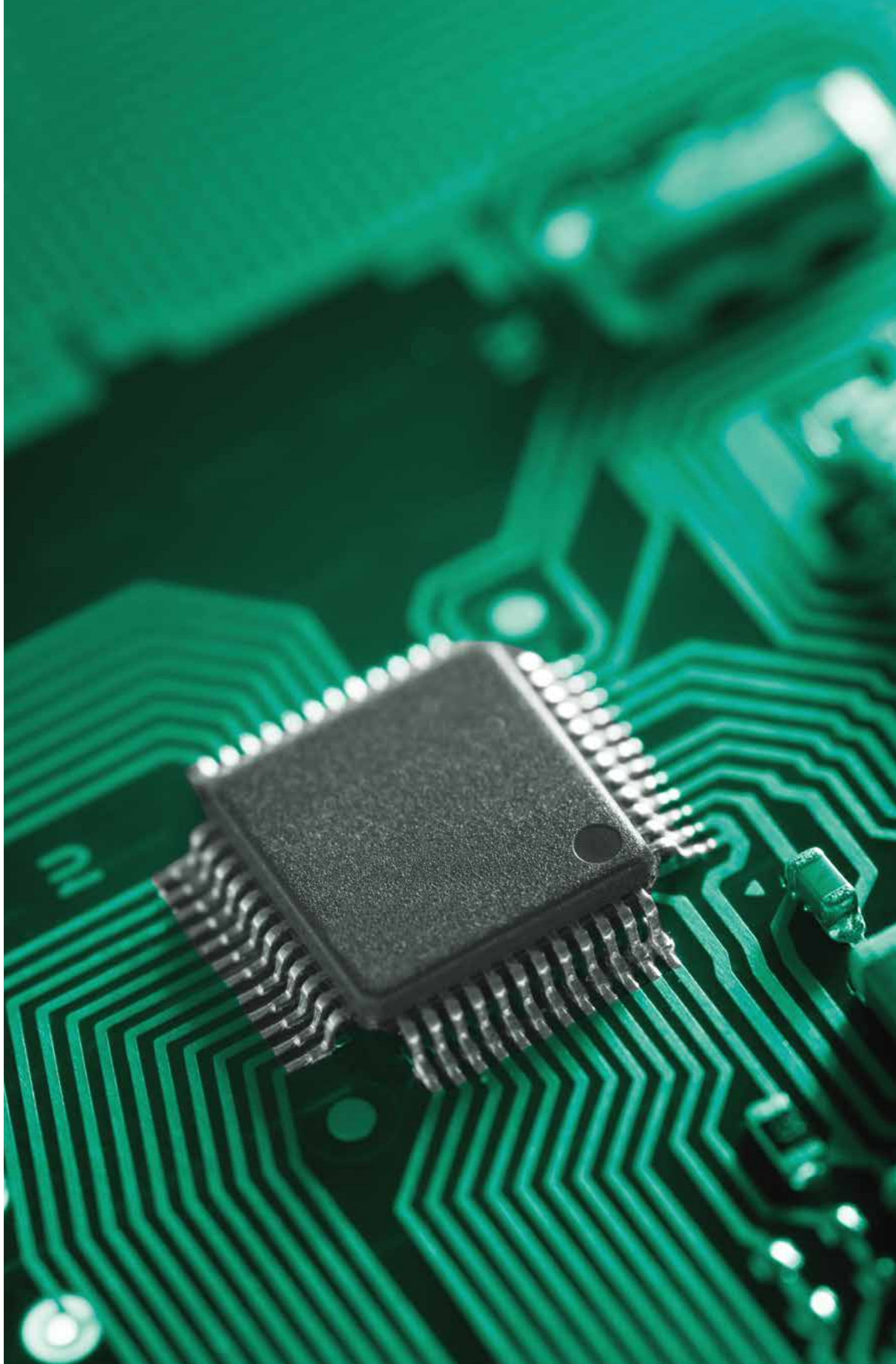
Remaining SCAD fuel consumption data for industry not included in this report are the manufacture of textiles, wearing apparel, leather and related products, wood and of products of wood and cork, computer, electronic and optical products, electrical equipment, machinery and equipment, motor vehicles, trailers and semi-trailers, other transport equipment, furniture, other products, repair and installation of machinery and equipment, water collection, treatment and supply, waste collection, treatment and disposal activities; materials recovery and remediation activities and other waste management services. Despite the number of these additional categories, the total fuel reported in this combined 'other' category only increased the SCAD fuel combustion total by 0.2 %, showing these categories to be insignificant for emissions. This indicates that the lacks of questionnaire data collection for these sub-sectors within this project have minimal effect on the result.

A Tier 1 or 2 approach was taken to estimate emissions from each facility (depending on the quality of the information available) using EMEP/EEA (2016) guidelines. For each sub-sector, EMEP/EEA (2016) calculate process emissions and fuel combustion emissions separately. Where both process and fuel combustion emissions are evolved simultaneously, and are difficult to separate, NMVOC, $PM_{2.5}$ and PM_{10} are generally attributed to process emissions, whilst NO_X, SO_X and CO are generally attributed to fuel combustion. This split is industry specific. For consistency across all sectors, if TPM was reported (and not $PM_{2.5}$ and PM_{10} separately), then it was assumed that $TPM=PM_{10}=PM_{2.5}$.

5.1.1 Calculating Industrial Process Emissions

The EMEP/EEA (2016) Tier 1 approach to calculate industrial process emissions is based on the multiplication of activity (production) data with an emission factor, as shown in Equation 3. $E_{pollutant}$ is the quantity of pollutant emitted during the year 2015, $AR_{production}$ is the activity data (production), and $EF_{pollutant}$ is the emission factor for that specific pollutant.

$$E_{pollutent} = AR_{production} \times EF_{pollutant} \quad \textit{Equation 3}$$



The EMEP/EEA (2016) Tier 2 approach to calculate industrial process emissions is shown in Equation 4. It is similar to the Tier 1 approach, but requires more technology specific information. $E_{pollutant}$ is the quantity of pollutant emitted during the year 2015, $\sum_{technologies}$ is the total for all technologies, $AR_{productiontechnology}$ is the technology specific activity data and $EF_{technologypollutant}$ is the emission factor for that specific technology and pollutant.

$$E_{pollutent} = \sum_{technologies} AR_{productiontechnology} \times EF_{technologypollutant} \qquad \textit{Equation 4}$$

Where possible, calculated values for each facility were modified based on the applied emission mitigation technologies used.

5.1.2 **Calculating Industrial Fuel Combustion Emissions**

The EMEP/EEA (2016) Tier 1 approach to calculate industrial fuel combustion emissions is based on the multiplication of activity (fuel consumption) data with an emission factor, as shown in Equation 5. Here, $E_{pollutant}$ is the quantity of pollutant emitted during the year 2015, $\sum_{fuels}$ is the total for all fuels combusted, $AR_{fuelconsumption}$ is the quantity of fuel used in industrial combustion and $EF_{fuel,pollutant}$ is the average emission factor for each pollutant for each unit of fuel type used. Combustion emission factors are sourced from the EMEP/EEA (2016) guidebook for general combustion in manufacturing and construction industries. Tier 1 manufacturing combustion emission factors are given by EMEP/EEA for e.g. solid, liquid and gaseous fuels.

$$E_{pollutent} = \sum_{fuels} AR_{fuelconsumption} \times EF_{fuel,pollutant} \qquad \textit{Equation 5}$$

The EMEP/EEA (2016) Tier 2 approach to calculate industrial fuel combustion emissions is similar to the Tier 1 approach, but requires more fuel or technology specific information. The annual emission is determined by activity data (fuel consumption) and an emission factor, as shown in Equation 6. E_i is the quantity of pollutant i emitted during the year 2015, $\sum_{i,j,k}$ is the total for pollutant i, source type, j, and fuel, k, $EF_{i,j,k}$ is the default emission factor of pollutant i, source type, j, and fuel k, and $A_{j,k}$ is the annual consumption of fuel k in source type j. Tier 2 in-process combustion emission factors are provided based on production data rather than actual fuel combustion quantities, since it is often a more available or relevant statistic.

$$E_i = \sum_{i,j,k} EF_{i,j,k} \times A_{j,k} \qquad \textit{Equation 6}$$

Where possible, calculated values for each facility were modified based on the applied emission mitigation technologies used.

5.2 Industry Emissions by Subsector

In the following sections it is presented a brief about the bottom-up analysis carried out for each of the main subsectors, including the emission factors used, and the emissions from any processes, as well as any fuel combusted, from industrial processing.

5.2.1 Asphalt Production

5.2.1.1 Method to Estimate Asphalt Production Emissions

Asphalt production emissions were calculated according to the guidelines from EMEP/EEA (2016) chapter 2.D.3.b, Road paving with asphalt. In asphalt production, an aggregate is mixed (and heated) with an asphalt binder (bitumen), resulting in both combustion and process emissions. Asphalt cement or liquefied asphalt may be used as the asphalt binder. Asphalt cement is heated prior to mixing with the aggregate in hot mix plants. Hot mix asphalt paving materials can be manufactured by batch mix plants, parallel flow (drum) mix plants, continuous mix plants and counter flow plants.

A Tier 2 emission factor approach was taken to estimate emissions from fuel combustion and the asphalt production process. Process and fuel combustion emissions were calculated separately based on the quantity of drum or batch mix asphalt produced, modified based on the applied emission mitigation technologies used. Most asphalt production reported was of batch mix type. Emission factors used in our study are shown in Table 7.

Operating facilities in the year 2015 in Abu Dhabi Emirate that contributed data for analysis included:

- Admak General Contracting Company WLL
- Al Jaber Asphalt Factory
- Copri Construction Enterprises Establishment
- Factory of Western Bainoona for Asphalt Manufacturing LLC
- Ghantoot Transport & Contracting Establishment
- Tarmac Abu Dhabi Limited Co - Al Mafraq branch
- Tarmac Abu Dhabi Limited Co - Al Ain branch

Combining submitted data from these facilities, asphalt production for the year 2015 included 1,909,369 t batch asphalt, and 5,015 t drum asphalt. Fuel combusted for processing included 404,730 GJ liquid fuel.

Table 7: Emission factors (g/t) for NMVOC, $PM_{2.5}$ and PM_{10} process emissions from asphalt production, and NO_x, CO and SO_2 emissions from fuel combustion (EEA/EMEP, 2016). Note: both process and fuel combustion emissions are calculated based on the quantity (t) of asphalt produced.

	Emission factors (g/t)					
	EF_{NMVOC}	$EF_{PM2.5}$	EF_{PM10}	EF_{NO_x}	EF_{CO}	EF_{SO2}
Process emissions (drum mix)	15	700	3,000			
Process emissions (batch mix)	16	100	2,000			
Fuel combustion (all)				35.6	200	17.7

5.2.1.21 Emissions from Asphalt Production

Emissions from asphalt production for the year 2015 are shown in Table 8.

Table 8: Emissions from asphalt production (t/yr) in Abu Dhabi Emirate in 2015, distributed by emission type (process or fuel combustion). Note: All values in the table are rounded to the nearest integer.

	Calculated emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
Process emissions (drum)	0	4	4			
Process emissions (batch)	31	191	344			
Fuel combustion (all)				68	383	34
TOTAL	31	194	347	68	383	34

5.2.2 Cement Production

5.2.2.1 Method to Estimate Cement Production Emissions

Cement production emissions were calculated according to the guidelines from EMEP/EEA (2016) chapter 2.A.1, Cement production. The production of cement involves four stages: 1) extraction and pre-processing of raw materials, 2) pyro-processing to produce clinker, 3) blending and grinding of clinker to cement, and 4) storage, packing and delivery of cement, resulting in both combustion and process emissions. Combustion emissions derive from clinker pyro-processing, which takes place in a kiln. In the Abu Dhabi Emirate, major producers of clinker and cement are the Emirates Cement Factory (ECF) and Al Ain Cement Factory (ACF).

A Tier 2 emission factor approach was taken to estimate emissions from fuel combustion and the cement production process. Process and fuel combustion emissions were calculated separately based on the quantity of clinker used, and the quantity of clinker produced, respectively, modified based on the applied emission mitigation technologies used. Fuel combustion emissions were not calculated based solely on the quantity of clinker used, since most facilities are assumed not to produce their own clinker through pyro-processing (evidenced by not reporting either fuel consumption or clinker production). Emission factors used in our study are shown in Table 9.

Operating facilities in the year 2015 in Abu Dhabi Emirate that contributed data for analysis included:

- Al Ain Cement Factory
- Arabian Cement Industry LLC
- National Cement Factory LLC
- Teba Cement Factory LLC

Combining submitted data from these facilities, cement production for the year 2015 was 4,432,766 t. 4,942,697 t clinker was used, of which 3,147,252 t clinker was produced in-house. Fuel combusted for processing included 10,285,588 GJ gaseous fuel.

Table 9: Emission factors (g/t) for $PM_{2.5}$ and PM_{10} process emissions from cement production, and NMVOC, NO_X, CO and SO2 emissions from fuel combustion (EEA/EMEP, 2016). Note: process emissions are based on the quantity (t) of clinker used, whilst fuel combustion emissions are based on the quantity (t) of clinker produced.

	Emission factors (g/t)					
	EF_{NMVOC}	$EF_{PM2.5}$	EF_{PM10}	EF_{NO_x}	EF_{CO}	EF_{SO2}
Process emissions		130	234			
Fuel combustion	18			1,241	1,455	374

5.2.2.2 Emissions from Cement Production

Emissions from cement production for the year 2015 are shown in Table 10.

Table 10: Emissions from cement production (t/yr) in Abu Dhabi Emirate in 2015, distributed by emission type (process or fuel combustion). Note: All values in the table are rounded to the nearest integer.

	Calculated emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
Process emissions		643	648			
Fuel combustion	57			3,906	4,579	1,177
TOTAL	57	643	648	3,906	4,579	1,177

5.2.3 Concrete Production

5.2.3.1 Method to Estimate Concrete Production Emissions

Concrete production (and ready mix) emissions were calculated according to the guidelines from EMEP/EEA (2016) chapter 2.A.1, Cement production, and the US EPA guidelines AP42 (2012) Section 11.12, Concrete batching. US EPA guidelines were additionally used for this sub-sector, since concrete production process emissions are not directly covered by EMEP/EEA (2016). The production of concrete is the process of mixing together cement, cement supplement, sand and aggregate with water. Process emissions (particulates) are emitted from various stages of the material transfer stages, material unloading stages, or material loading/mixing stages. Combustion emissions may also result from facility activity.

A mixed Tier 1/2 emission factor approach was taken to estimate emissions from fuel combustion and the concrete production process. Process emissions (particulate matter) for concrete/ready mix production were calculated based on the quantity of cement, cement supplement, sand and aggregate loaded, used and mixed, modified based on the applied emission mitigation technologies (equivalent Tier 2 approach to EMEP/EEA). Emission factors for material transfer were the same for both truck mix and central mix concrete, aside from the final mixer or truck loading step. Concrete production at three facilities in the Abu Dhabi Emirate was specified as central mix in questionnaires. Due to a lack of data, concrete production at other facilities was assumed truck mix, to allow for conservative emission estimates (since the truck mix loading emission factor is approximately 2x higher than the mixer loading emission factor). Combustion emissions were based on the quantity of fuel combusted according to gaseous and liquid types (Tier 1 approach) although only a small quantity of fuel combustion was reported for a few facilities. No Tier 2 emission factors are available from EMEP/EEA (2016) for combustion during concrete production. Only liquid fuel use was applicable for concrete production in Abu Dhabi Emirate. Emission factors used in our study are shown in Table 11.

Operating facilities in the year 2015 in Abu Dhabi Emirate that contributed data for analysis included:

- Al Ain Ceramic Factory
- Al Falah Readymix LLC (Branch 3)
- Al Falah Readymix LLC (Branch 4)
- Bin Fadel Al Mazrouei Ready Mix Est.
- Cement Enterprises & Ready Mix (CEMIX) LLC
- CEMEX Super Mix LLC
- City Block Cement Products Factory
- Eugene International LLC
- Excellent Pipes Company LLC
- Quick Mix Beton LLC
- Quick Mix Beton LLC (Branch 1)
- Quick Mix Beton LLC (Branch 2)
- Redco Bin Juma Ready Mix Factory LLC
- Sodamco Emirates Factory for Building Material LLC
- Square General Precast LLC
- Synaxis Readymix LLC
- Technical Ready Mix Concrete Co
- Techno Cast Precast LLC
- Tri Star Concrete Products Factory LLC

Combining submitted data from these facilities, concrete production for the year 2015 used 6,185,389 t total combined cement, sand, cement supplement and aggregate. Fuel combusted for processing included 18,050 GJ liquid fuel.

Table 11: Emission factors (kg/t) for PM_{10} process emissions from concrete production steps (US EPA, 2012), and NMVOC, $PM_{2.5}$, PM_{10}, NO_X, CO and SO_2 emission factors (g/GJ) from fuel combustion (EEA/EMEP, 2016). Note: Emission factors are uncontrolled.

	Emission factors					
	EF_{NMVOC}	$EF_{PM2.5}$	EF_{PM10}	EF_{NO_x}	EF_{CO}	EF_{SO2}
Process emissions (aggregate transfer) (kg/t aggregate loaded)			0.0017			
Process emissions (sand transfer) (kg/t sand loaded)			0.00051			
Process emissions (cement unloading) (kg/t cement)			0.24			
Process emissions (cement supplement unloading) (kg/t cement supplement)			0.65			
Process emissions (Weigh hopper loading) (kg/t aggregate and sand)			0.0013			
Process emissions (Mixer loading – central mix) (kg/t cement and supplement)			0.078			
Process emissions (Mixer loading – truck mix) (kg/t cement and supplement)			0.155			
Liquid fuel combustion (g/GJ)	25	20	20	513	66	47

5.2.3.2 Concrete Production Emissions

Emissions from concrete production for the year 2015 are shown in Table 12.

Table 12: Emissions from concrete production (t/yr) in Abu Dhabi Emirate in 2015, distributed by emission type (process or fuel combustion). Note: $PM_{2.5}$ process emissions are assumed equal to PM_{10}. All values in the table are rounded to the nearest integer.

	Emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
Process emissions (aggregate transfer)		6	6			
Process emissions (sand transfer)		1	1			
Process emissions (cement unloading)		38	38			
Process emissions (cement supplement unloading)		411	411			
Process emissions (Weigh hopper loading)		6	6			
Process emissions (Mixer loading – central mix)		1	1			
Process emissions (Mixer loading – truck mix)		167	167			
Fuel combustion (liquid)	0	0	0	9	1	1
TOTAL	0	630	630	9	1	1

5.2.4 Iron and Steel Production

5.2.4.1 Method to Estimate Iron and Steel Production Emissions

Iron and steel production emissions were calculated according to the guidelines from EMEP/EEA (2016) chapter 2.C.1, Iron and steel production. The main processes for iron and steel production include sinter production, pellet production, iron making, steel making, steel casting and any combustion of blast furnace and coke oven gases for other purposes. The main processes may occur at an 'integrated' facility, typically with blast furnaces, basic oxygen steel making furnaces or open hearth furnaces. Process emissions and combustion emissions may result from iron and steel production facilities, with most combustion emissions produced during sintering. Located in the Abu Dhabi Emirate, Emirates Steel is the UAE`s leading primary producer of Direct Reduced Iron (DRI), steel, and iron and steel products.

Continuous Emission Measurement (CEM) data in mg/Nm3 was submitted by Emirates Steel, at a disaggregated (stack) level for NO_X, SO_X, CO and dust. However, since measurements lacked the volume flow to convert mg/Nm3 to t/yr, and most stacks had no associated measurements, this Tier 3 data was not used. Instead, PM_{10}, NO_2, NO_X, CO and SO_X emission data was sourced from the Emirates Steel environmental impact assessment (Emirates Steel, 2015). $PM_{2.5}$ emissions were calculated from PM_{10}, based on the ratio of $PM_{2.5}$:PM_{10} emission factors for pig iron production in the EMEP/EEA (2016) guidebook. Due to a lack of data, a Tier 1/2 approach was taken to estimate Emirates Steel NMVOC emissions from fuel combustion and the iron and steel production process, based on the quantity of fuel combusted and the quantity of raw pig iron and primary steel (electric arc) produced.

Other facilities responding to the questionnaire re-worked iron and steel into products, and did not produce primary or secondary iron and steel. Thus, process emissions for metal production are not applicable for these activities under EMEP/EEA (2016) iron and steel production guidelines. Combustion emissions for any general activity within these facilities were calculated based on the quantity of fuel combusted according to gaseous and liquid types (Tier 1 approach). The emission factors used in our study are shown in Table 13.

Table 13: Emission factors (g/t) for NMVOC, $PM_{2.5}$, PM_{10}, NO_X, CO and SO_2 process emissions from iron and steel production, and NMVOC, $PM_{2.5}$, PM_{10}, NO_X, CO and SO_2 emissions (g/GJ) from fuel combustion (EEA/EMEP, 2016).

	Emission factors					
	EF_{NMVOC}	$EF_{PM2.5}$	EF_{PM10}	EF_{NO_x}	EF_{CO}	EF_{SO2}
Process emissions (pig iron) (g/t)		25	40			
Process emissions (steel, electric arc) (g/t)	46	21	24	130	1,700	60
Gaseous fuel combustion (g/GJ)	23	0.78	0.78	74	29	0.67
Liquid fuel combustion (g/GJ)	25	20	20	513	66	47

5.2.4.2 Iron and Steel Production Emissions

Emissions from iron and steel production for the year 2015 are shown in Table 14.

Table 14: Emissions from iron and steel production (t/yr) in Abu Dhabi Emirate in 2015, distributed by emission type (process or fuel combustion). Note: All values in the table are rounded to the nearest integer. * indicates that Emirates Steel NO_X represents the summed value of reported NO_2 and NO_X emissions.

	Emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
Primary iron and steel production (Emirates Steel)	1,090	1,004	1,607	1,400*	23,827	2,034
Fuel combustion (general activity, gaseous fuel)	9	0	0	30	12	0
Fuel combustion (general activity, liquid fuel)	4	3	3	90	12	8
TOTAL	1,103	1,008	1,610	1,519	23,850	2,043

5.2.5 Aluminium Production

5.2.5.1 Method to Estimate Aluminium Production Emissions

Aluminium production emissions were calculated according to the guidelines from EMEP/EEA (2016) chapter 2.C.3, Aluminium production. The main processes for primary aluminium production include electrolytic reduction, refining and casting, whilst the production of secondary aluminium includes melting, refining and casting. Process emissions and combustion emissions may result from aluminium production facilities. Combustion emissions derive mainly from the production of alumina, or re-melting furnace, but may also derive from other processing activities at a facility. Within the Abu Dhabi Emirate, all primary aluminium production occurs using prebake technology, at Emirates Global Aluminium (EGA).

Tier 3 standard emission loadings to the atmosphere per quarter year, with units of t/qt (deriving from Continuous Emission Measurement (CEM) and manual monitoring data), was submitted by EGA. Data was supplied at a disaggregated (stack) level. In general, pollutants reported were NO_X, SO_2, CO, VOC and total particulate matter (TPM). Lacking other data, VOC was assumed to equal NMVOC, and TPM was assumed to equal $PM_{2.5}$ and PM_{10}. Submitted emissions were divided into smelter (process) and power plant (combustion) EGA facilities. Emissions deriving from EGA production of electricity were included in this subsector, and not under 'Electricity Production', since all electricity produced was consumed by EGA for aluminium production.

One facility reported the production of secondary aluminium. For this facility, a Tier 2 approach was taken to estimate process emissions, based on the quantity of secondary aluminium produced. Tier 2 emission factors for combustion during secondary aluminium production are available from EMEP/EEA (2016), based on the quantity of secondary aluminium produced. Partial combustion emissions could therefore be estimated, but since the facility also reported other types of processing activity not covered by this approach, this does not represent complete combustion activity. Therefore a Tier 1 approach was used to estimate combustion emissions for the facility based on the reported quantity of liquid fuel combusted. Calculated combustion emissions with Tier 2 method are around an order of magnitude lower than Tier 1, so calculations here represent a worst-case scenario. For other aluminium facilities, who do not produce primary or secondary aluminium but e.g. work aluminium into products, a Tier 1 approach was taken to estimate emissions based on the quantity of liquid or gaseous fuel combusted. Process emissions are not applicable for these activities under EMEP/EEA (2016) aluminium production guidelines. Emission factors used in our study are shown in Table 15.

Operating facilities in the year 2015 in Abu Dhabi Emirate that contributed data for analysis included:

- Emirates Aluminium Company Limited PJSC
- Al Jaber Aluminium Extrusions LLC
- Al Jazira Metal Industries Co. LLC

Combining submitted data from these facilities, total primary aluminium production was 1,349,251 t for the year 2015. Secondary aluminium production was 5,045 t. Fuel combusted by all facilities for processing (including for the production of secondary materials) included 156,530,088 GJ gaseous fuel and 167,217 GJ liquid fuel.

Table 15: Emission factors for NMVOC, $PM_{2.5}$, PM_{10}, NO_X, CO and SO_2 emissions from process and fuel combustion (EEA/EMEP,2016).

	Emission factors (g/GJ)					
	EF_{NMVOC}	$EF_{PM2.5}$	EF_{PM10}	EF_{NO_x}	EF_{CO}	EF_{SO2}
Process emissions (secondary aluminium) (kg/t)		0.55	1.4			
Gaseous fuel combustion (g/GJ)	23	0.78	0.78	74	29	0.67
Liquid fuel combustion (g/GJ)	25	20	20	513	66	47

5.2.5.2 Aluminium Production Emissions

Emissions from aluminium production for the year 2015 are shown in Table 16. The CO:NO_X ratio reported by EGA measurements (130:1) is close to the CO:NO_X ratio suggested from Tier 2 emission factors for prebake cells from EMEP (120:1).

Table 16: Emissions from aluminium production (t/yr) in Abu Dhabi Emirate in 2015, distributed by emission type (process or fuel combustion). Note: All values in the table are rounded to the nearest integer. * indicates that VOC was reported by EGA, and not NMVOC.

	Emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
Process emissions (primary aluminium, EGA)	5*	828	828	715	93,003	9,917
Process emissions (secondary aluminium)	0	3	7			
Fuel combustion (secondary aluminium and general activity, gaseous fuel)	1	0	0	2	1	0
Fuel combustion (secondary aluminium and general activity, liquid fuel)	3	2	2	58	7	5
Fuel combustion (primary aluminium, EGA)	0*	267	267	1,668	356	236
TOTAL	8	1,100	1,104	2,443	93,367	10,158

5.2.6 Copper Production

5.2.6.1 Method to Estimate Copper Production Emissions

Copper production emissions were calculated according to the guidelines from EMEP/EEA (2016) chapter 2.C.7.a, Copper production. The main processes for primary/secondary copper production may include roasting or drying of ore, smelting, converting and fire refining. Process emissions and combustion emissions may result from any of these stages. Additional emissions may also derive from other copper processing activities at a facility. No primary or secondary copper production was reported in the Abu Dhabi Emirate, but several facilities reported working copper into products. A Tier 1 approach was taken to estimate emissions based on the quantity of liquid or gaseous fuel combusted. Process emissions are not applicable for these activities under EMEP/EEA (2016) copper production guidelines. Emission factors used in our study are shown in Table 17.

Operating facilities in the year 2015 in Abu Dhabi Emirate that contributed data for analysis included:

- Dubai Cable Company Pvt. LTD Abu Dhabi (Branch 1)
- Union Copper Rod LLC

Combining submitted data from these facilities, fuel combusted for processing (including for the production of secondary materials) for the year 2015 included 17,819 GJ liquid fuel and 573,123 GJ gaseous fuel.

Table 17: Emission factors (g/GJ) for NMVOC, $PM_{2.5}$, PM_{10}, NO_X, CO and SO_2 emissions from fuel combustion (EEA/EMEP, 2016).

	Emission factors (g/GJ)					
	EF_{NMVOC}	$EF_{PM2.5}$	EF_{PM10}	EF_{NO_x}	EF_{CO}	EF_{SO2}
Gaseous fuel combustion	23	0.78	0.78	74	29	0.67
Liquid fuel combustion	25	20	20	513	66	47

5.2.6.1 Copper Production Emissions

Emissions from copper production for the year 2015 are shown in Table 18.

Table 18: Emissions from copper production (t/yr) in Abu Dhabi Emirate in 2015, distributed by emission type (gaseous or liquid fuel combustion). Note: All values in the table are rounded to the nearest integer.

	Calculated emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_x	CO	SO_2
Fuel combustion (gaseous)	13	0	0	42	17	0
Fuel combustion (liquid)	0	0	0	9	1	1
TOTAL	14	1	1	52	18	1

5.2.7 Chemical Production

5.2.7.1 Method to Estimate Chemical Production Emissions

Chemical production emissions were calculated according to the guidelines from EMEP/EEA (2016) chapter 2.B, Chemical industry and 2.D.3.g, Chemical products. These are wide sub-sectors describing the production of a range of chemical products, including many differing units or manufacturing processes. Process emissions and combustion emissions may result from a unit or manufacturing process.

A mixed Tier 1/2 approach was taken to estimate emissions, based on the quantity of products produced (and associated technology), and the quantity of liquid or gaseous fuel combusted. Chemical production facilities in Abu Dhabi Emirate reported the production of fertiliser, paints, gases (e.g. N_2, liquid O_2 or CO_2 (dry ice)), pharmaceuticals and other chemicals (e.g. AlF3). Process emissions from fertiliser and paints were estimated according to Tier 2 method. Process emissions from the pharmaceutical industry were estimated using both Tier 1 and 2 method; Tier 1 where only the quantity of products was known (estimated as 'chemical products'), and Tier 2 where the quantity of solvents used was known. No process emissions for many types of chemical product (e.g. gases or AlF3) are calculated under EMEP/EEA (2016) guidelines. Fuel combustion was also reported by many facilities, and were calculated using a Tier 1 approach based on the quantity of liquid or gaseous fuel combusted. No Tier 2 emission factors are available from EMEP/EEA (2016) for combustion during these types of chemical production. Emission factors used in our study are shown in Table 19.

Operating facilities in the year 2015 in Abu Dhabi Emirate that contributed data for analysis included:

- Abba Botanical Preparations Factory
- Abu Dhabi Fertilizer Industries Co. WLL
- Air Liquide Emirates for Industrial Gases
- Ajwaa Emirates Gases Co. LLC
- Al Shefa Veterinary Medicines Factory LLC
- Emirates Western Oil Well Drilling and Maintenance Factory LLC. (Industrial Branch)
- Gulf Cryo Industrial Gases Company LLC
- Gulf Fluor LLC
- National Paints Factories Co. LLC (Abu Dhabi branch)
- Neopharma LLC

- Pan Gulf Labs Solutions Factory
- Saad H. Abukhadra and Co.
- Super Tech Dry Ice Manufacturing LLC
- Tam Perfumes Factory
- Union International Bitumen Co. LLC
- Universal Paint and Chemical Industries Chemipaint LLC

Combining submitted data from these facilities, fertiliser, paint and pharmaceuticals production were 45,777 t, 23,304 t and 496 t, respectively, for the year 2015. 70 kg of solvents were reported consumed.

Fuel combusted by all facilities for processing included 159,951 GJ gaseous fuel and 29,000 GJ liquid fuel.

Table 19: Emission factors (kg/t or g/kg) for NMVOC, $PM_{2.5}$ and PM_{10}, process emissions from chemical production, and NMVOC, $PM_{2.5}$, PM_{10}, NO_X, CO and SO_2 emissions (g/GJ) from fuel combustion (EEA/EMEP, 2016).

	Emission factors (g/GJ)					
	EF_{NMVOC}	$EF_{PM2.5}$	EF_{PM10}	EF_{NO_X}	EF_{CO}	EF_{SO2}
Chemical products (kg/t)	10					
Phosphate fertilizer (kg/t)		0.18	0.24			
Paints (kg/t)	11					
Pharmaceuticals (g/kg solvent used)	300					
Gaseous fuel combustion (g/GJ)	23	0.78	0.78	74	29	0.67
Liquid fuel combustion (g/GJ)	25	20	20	513	66	47

5.2.7.2 Chemical Production Emissions

Emissions from chemical production for the year 2015 are shown in Table 20.

Table 20: Emissions from chemical production (t/yr) in Abu Dhabi Emirate in 2015, distributed by emission type (production process or fuel combustion). Note: All values in the table are rounded to the nearest integer.

	Calculated emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
Phosphate fertiliser		8	8			
Paints	256					
Chemical products	5					
Pharmaceuticals	0					
Fuel combustion (gaseous)	4	0	0	12	5	0
Fuel combustion (liquid)	1	1	1	15	2	1
TOTAL	266	9	9	27	7	1

5.2.8 Food and Beverage Production

5.2.8.1 Method to Estimate Food and Beverage Production Emissions

Food and beverage production emissions were calculated according to the guidelines from EMEP/EEA (2016) chapter 2.H.2, Food and beverages industry. Emissions from food manufacturing include all processes in the food production chain that occur after the slaughtering of animals and crop harvesting. Process emissions and combustion emissions may result from food and beverage industry. A mixed Tier 1/2 approach was taken to estimate emissions, based on the quantity and type of products produced, and the quantity of liquid or gaseous fuel combusted. Food production facilities in Abu Dhabi Emirate reported the production of white and brown bread products, cake products, meat products, animal feed, other food (e.g. dates and date products), and the production of drinking water. Grain handling was also reported. Process emissions from these activities were estimated according to Tier 2 method. No process emissions for bottled water production or date products are calculated under EMEP/EEA (2016) guidelines. Liquid fuel combustion was also reported by many facilities, with emissions calculated using a Tier 1 approach based on the quantity of liquid fuel combusted. No Tier 2 emission factors are available from EMEP/EEA (2016) for combustion during these types of food and beverage production. Emission factors used in our study are shown in Table 21.

Operating facilities in the year 2015 in Abu Dhabi Emirate that contributed data for analysis included:

- Al Ahlia Gulf Line General Trading Company (PVT) Ltd LLC
- Al Furat Drinking Water LLC
- Al Redwan Pure Water
- Al Foah Dates Factory
- Alghadeer Drinking Water Factory
- Golden Spike and Wheat EST
- One Foods (Alwar Food Products Factory LLC)
- Super Awafi Mineral Water Co. LLC
- Warsan Animals Food Manufacturing (Al Ain Branch)

Combining submitted data from these facilities, animal feed, meat, white bread, brown bread and cake production were 1,150 t, 19,485 t, 1,636 t, 393 t, and 583 t, respectively, for the year 2015. The quantity of grain handled reported was 1,151 t. Fuel combusted by all facilities for processing included 108,753 GJ liquid fuel.

Table 21: Emission factors (kg/t or g/t) for NMVOC and PM_{10}, process emissions from food and beverage production, and NMVOC, $PM_{2.5}$, PM_{10}, NO_X, CO and SO_2 emissions (g/GJ) from fuel combustion (EEA/EMEP, 2016).

	Emission factors					
	EF_{NMVOC}	$EF_{PM2.5}$	EF_{PM10}	EF_{NO_X}	EF_{CO}	EF_{SO2}
Animal feed (kg/t)	1					
Handling of agricultural products (g/t)			24			
Meat/fish (kg/t)	0.3					
White bread (kg/t)	4.5					
Brown bread (kg/t)	3					
Cakes, biscuits and breakfast cereals (kg/t)	1					
Liquid fuel combustion (g/GJ)	25	20	20	513	66	47

5.2.8.2 Food and Beverage Production Emissions

Emissions from food and beverage production for the year 2015 are shown in Table 22.

Table 22: Emissions from food and beverage production (t/yr) in Abu Dhabi Emirate in 2015, distributed by emission type (production process or fuel combustion). Note: All values in the table are rounded to the nearest integer.

	Calculated emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
Animal feed	1					
Handling of agricultural products			0			
Meat/fish	6					
White bread	7					
Brown bread	1					
Cakes, biscuits and breakfast cereals	1					
Fuel combustion (liquid)	3	2	2	56	7	5
TOTAL	19	2	2	56	7	5

5.2.9 Paper Production

5.2.9.1 Method to Estimate Paper Production Emissions

Paper production emissions were calculated according to the guidelines from EMEP/EEA (2016) chapter 2.H.1, Pulp and paper industry. Pulp and paper production collectively consists of three main processing steps, 1) pulping, 2) bleaching and 3) paper production. In the Abu Dhabi Emirate, however, pulp is not made in-house. Instead, major paper-making processes include the dilution of purchased pulp, high-density pulp cleaning, refining, low-density cleaning, forming and drying.

A Tier 1 emission factor approach was taken to estimate emissions both from fuel combustion and the paper production process. Process and fuel combustion emissions were calculated separately based on the quantity of paper produced. Emission factors used in our study are shown in Table 23, sourced from the EMEP/EEA (2016) guidebook. The process emission factors that we use cover all steps of the paper manufacturing process (with emissions arising not just from pulp manufacturing, but also the paper production step itself). The reporting entities in Abu Dhabi Emirate did not make their pulp in-house, but since there are no available separated emission factors for different stages of the paper manufacture process from EMEP/EEA (2016) guidebook, the combined emission factor was applied to them. Therefore there is associated uncertainty with the result, and the process emissions calculated represent a 'worst-case-scenario' estimate for these entities.

Operating facilities in the year 2015 in Abu Dhabi Emirate that contributed data for analysis included:

- Abu Dhabi National Paper Mill LLC
- Crown Paper Mill LTD (Abu Dhabi Branch)

Combining submitted data from these facilities, paper production was 96,812 t for the year 2015. Fuel combusted by all facilities for processing included 546,029 GJ gaseous fuel.

Table 23: Emission factors (kg/t) for NMVOC, $PM_{2.5}$ and PM_{10} process emissions from paper production, and NO_x, CO and SO_2 emissions (g/t) from fuel combustion (EEA/EMEP, 2016). Note: both process emissions and fuel combustion emissions are based on the quantity of pulp (t) produced.

	Emission factors					
	EF_{NMVOC}	$EF_{PM2.5}$	EF_{PM10}	EF_{NO_x}	EF_{CO}	EF_{SO2}
Process emissions (kg/t air dried pulp)	2	0.6	0.8	1	5.5	2
Fuel combustion (g/t)				1369	1940	316

5.2.9.2 Paper Production Emissions

Emissions from paper production for the year 2015 are shown in Table 24.

Table 24: Emissions from paper production (t/yr) in Abu Dhabi Emirate in 2015, distributed by emission type (process or fuel combustion). Note: All values in the table are rounded to the nearest integer.

	Calculated emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
Process emissions	194	58	77	97	532	194
Fuel combustion				133	188	31
TOTAL	194	58	77	229	720	224

5.2.10 Plastic Production

5.2.10.1 Method to Estimate Plastic Production Emissions

Plastic production emissions were calculated according to the guidelines from EMEP/EEA (2016) chapter 2.B, Chemical industry. Plastic production is dealt with separately to other chemical production facilities due to the number of plastic product producers in the Emirate. This sub-sector describes the production of a range of plastic materials (e.g. polyethylene, polystyrene, polypropylene), and the chemical monomers used to make them, from unit or manufacturing processes. It also includes the manufacturing of plastic products from these materials. Process emissions and combustion emissions may result from plastic production.

A mixed Tier 1/2 approach was taken to estimate emissions, based on the quantity and type of products produced, and the quantity of liquid or gaseous fuel combusted. Of the many plastic manufacturing facilities in Abu Dhabi Emirate, almost all reported that they use pre-produced plastic materials to produce plastic products. Process emissions are not applicable for these facilities under EMEP/EEA (2016) guidelines, and only fuel combustion emissions were calculated using Tier 1 method (based on the quantity of liquid or gaseous fuel combusted). One facility reported primary expandable polystyrene production from the monomer, for which process emissions were additionally calculated using a Tier 2 approach. Emission factors used in our study are shown in Table 25.

Operating facilities in the year 2015 in Abu Dhabi Emirate that contributed data for analysis included:

- Abu Dhabi Pipe Factory LLC
- Abu Mansoor Plastic Factory
- Al Mimari Industrial Co. LLC
- Al Ain Acrylic Tubs Factory
- Cosmoplast Industrial Co. LLC (Branch 1 of Abu Dhabi)
- Electronic and Engineering Industries Co. LLC
- Emirates Preinsulated Pipes Industries LLC
- Integral Plastic Industries Co. LLC
- Karemo Plastic Industry
- M J Additive International Industry (SENTEC) LLC
- Majestic Plast Plastic Industries
- SHUAA Paper & Plastics Products Co.
- Styropack For Plastic Factory LLC
- Union Pipes Industry LLC

Combining submitted data from these facilities, polystyrene production (from the monomer) was 3,311 t for the year 2015. Fuel combusted by all facilities (including secondary processing of plastic material) included 76,023 GJ gaseous fuel and 586 GJ liquid fuel.

Table 25: Emission factors (kg/t) for NMVOC, $PM_{2.5}$ and PM_{10}, process emissions from plastic production, and NMVOC, $PM_{2.5}$, PM_{10}, NO_X, CO and SO_2 emissions (g/GJ) from fuel combustion (EEA/EMEP, 2016). Note: * indicates that the emission factor was for total suspended particles (TSP), and it was assumed that TSP=PM_{10}=$PM_{2.5}$.

	Emission factors					
	EF_{NMVOC}	$EF_{PM2.5}$	EF_{PM10}	EF_{NO_X}	EF_{CO}	EF_{SO2}
Polystyrene (expandable) (kg/t)	3.2	0.03*	0.03*			
Gaseous fuel combustion (g/GJ)	23	0.78	0.78	74	29	0.67
Liquid fuel combustion (g/GJ)	25	20	20	513	66	47

5.2.10.2 Plastic Production Emissions

Emissions from plastic production for the year 2015 are shown in Table 26.

Table 26: Emissions from plastic production (t/yr) in Abu Dhabi Emirate in 2015, distributed by emission type (production process or fuel combustion). Note: All values in the table are rounded to the nearest integer.

	Calculated emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
Polystyrene (expandable)	11	0	0			
Fuel combustion (gaseous)	2	0	0	6	2	0
Fuel combustion (liquid)	0	0	0	0	0	0
TOTAL	12	0	0	6	2	0

5.2.11 Printing

5.2.11.1 Method to Estimate Printing Emissions

Printing emissions were calculated according to the guidelines from EMEP/EEA (2016) chapter 2.D.3.h, Printing. Printing involves the use of inks which may contain organic solvents, and may also require the use of cleaning solvents and organic dampeners. Types include relief, offset, gravure, stencil and digital printing. Process emissions (NMVOC) result from this sub-sector.

A Tier 2 approach was taken to estimate process emissions, based on the quantity of ink used for printing and the technology used. Both heat set offset and flexography printing were reported in Abu Dhabi Emirate. No fuel combustion was reported for this sub-sector. Emission factors used in our study are shown in Table 27.

Operating facilities in the year 2015 in Abu Dhabi Emirate that contributed data for analysis included:

- Emirates Printing Forms EST

Use of ink included 167,976 kg for flexography, and 6,600 kg for offset printing.
No fuel combustion was reported.

Table 27: Emission factors (g/kg ink) for NMVOC process emissions from printing (EEA/EMEP, 2016).

	Emission factors (g/kg)					
	EF_{NMVOC}	$EF_{PM2.5}$	EF_{PM10}	EF_{NO_x}	EF_{CO}	EF_{SO2}
Heat set offset printing	730					
Flexography (small)	900					

5.2.11.2 Printing Emissions

Emissions from printing for the year 2015 are shown in Table 28.

Table 28: Process emissions from printing (t/yr) in Abu Dhabi Emirate in 2015, distributed by emission type (technology). Note: All values in the table are rounded to the nearest integer.

	Calculated emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
Heat set offset printing	5					
Flexography (small)	151					
TOTAL	156					

5.3 Industry Summary - Total Emissions

Emissions from the total industry sector for the year 2015 are shown in Table 29. In addition, the contribution from each sub-sector to the total of each pollutant is shown in Figure 10.

Analysis shows that key emitting industries for the Abu Dhabi Emirate were aluminium, iron and steel and cement and concrete sub-sectors. The aluminium industry contributed the majority of total SO_X (74 %), CO (76 %), and $PM_{2.5}$ (30 %), as well as a significant quantity of NO_X (29 %) and PM_{10} (25 %). The iron and steel industry contributed the majority of NMVOC (59 %), and PM_{10} (36 %), and a significant quantity of NO_X (18 %) and $PM_{2.5}$ (28 %). The cement industry contributed the majority of NO_X emissions (47 %), and a significant quantity of $PM_{2.5}$ (18 %), PM_{10} (15 %) and SO_X (9 %). The concrete and ready mix industry contributed a significant amount of $PM_{2.5}$ (17 %) and PM_{10} (14 %).

Table 29: Emissions from the industrial processing sector (t/yr) in Abu Dhabi Emirate in 2015, distributed by sub-sector. Note: All values in the table are rounded to the nearest integer.

	Emissions (t/yr)					
	NMVOC	$PM_{2.5}$	PM_{10}	NO_X	CO	SO_2
Aluminium	8	1,100	1,104	2,443	93,367	10,158
Asphalt	31	194	347	68	383	34
Cement	57	643	648	3,906	4,579	1,177
Chemicals	266	9	9	27	7	1
Concrete	0	630	630	9	1	1
Copper	14	1	1	52	18	1
Food and beverage	19	2	2	56	7	5
Iron and steel	1,103	1,008	1,610	1,519	23,850	2,043
Paper	194	58	77	229	720	224
Plastic	12	0	0	6	2	0
Printing	156	0	0	0	0	0
TOTAL	1,859	3,645	4,429	8,315	122,934	13,645

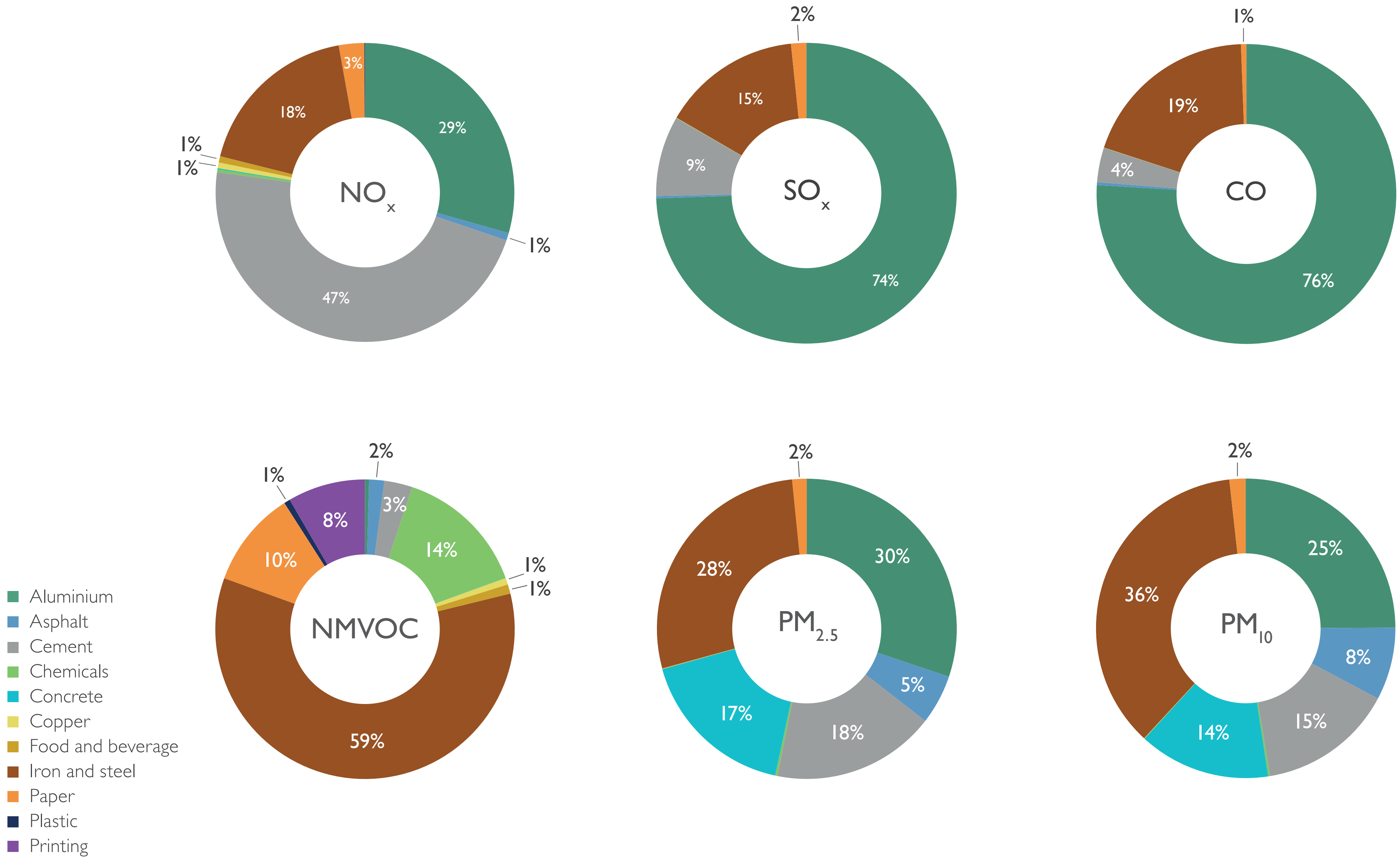


Figure 22: NMVOC, $PM_{2.5}$, PM_{10}, NO_x, CO and SO_2 emissions from industrial processing in Abu Dhabi Emirate in 2015, distributed by sub-sector. Sub-sectors contributing <1 % are not labelled on the figures for clarity.

Road Transport Sector

6 Road Transport Sector

Road transportation is an important catalyst of economic development in the Emirate, and new transport means are being created to keep pace with the ongoing urban developments. Continuous upgrading of infrastructures are taken place and consequently, the updating of emissions from this sector is essential. Emissions from road transport are associated to fuel used for road travel (i.e. motor petrol, CNG, gas/diesel oil). In the emission inventory update, a bottom-up method has been selected where emissions are estimated based on detailed information defined at the road network as described in the following chapters.

6.1 Method to Estimate Road Transport Emissions

Emissions from road transport were estimated for NO_X, PM, SO_2, CO, and NMVOC at each road link, based on the method and input data described below.

A. Road Network

Emissions from on-road traffic were estimated at the road link using the road network for Abu Dhabi Emirate provided by the Department of Transport (DoT) (Figure 23). The road network was provided in a shapefile containing specific information at the road link level, such as road classes and average daily traffic (ADT) of different vehicles classes. A detailed description of these variables is presented in the following sections.

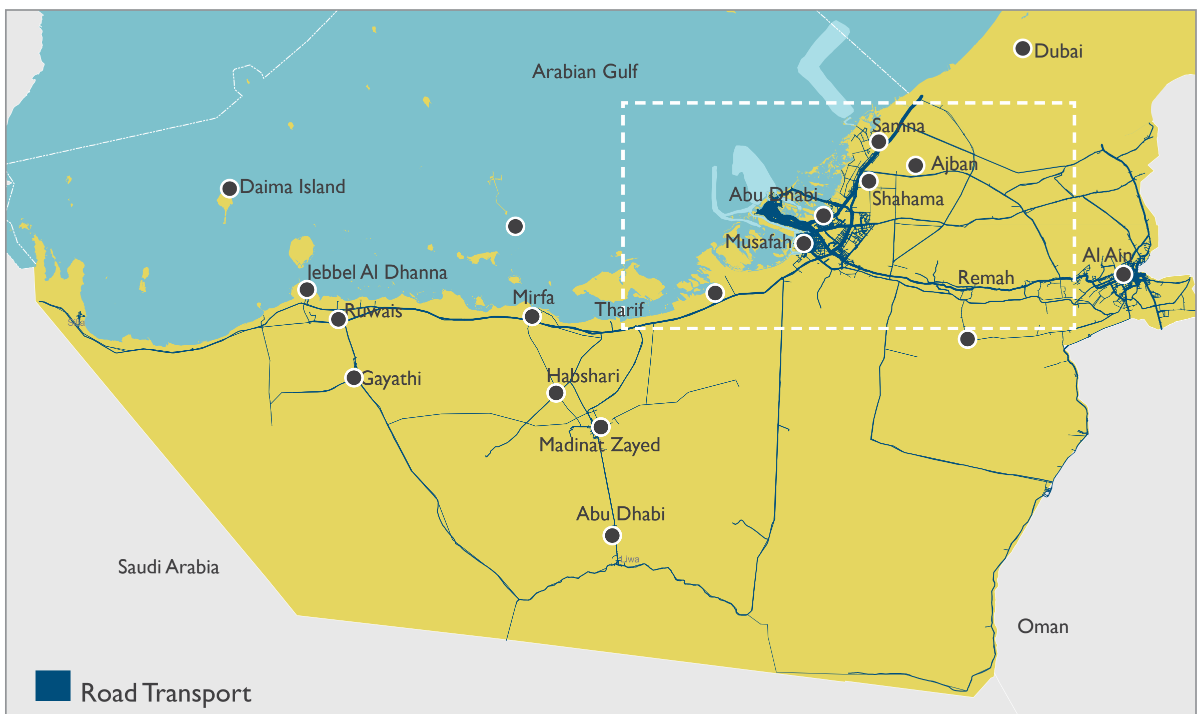


Figure 23: Part of the road network in Abu Dhabi Emirate used for estimating traffic emissions at the road link, and the location of the main population centres.

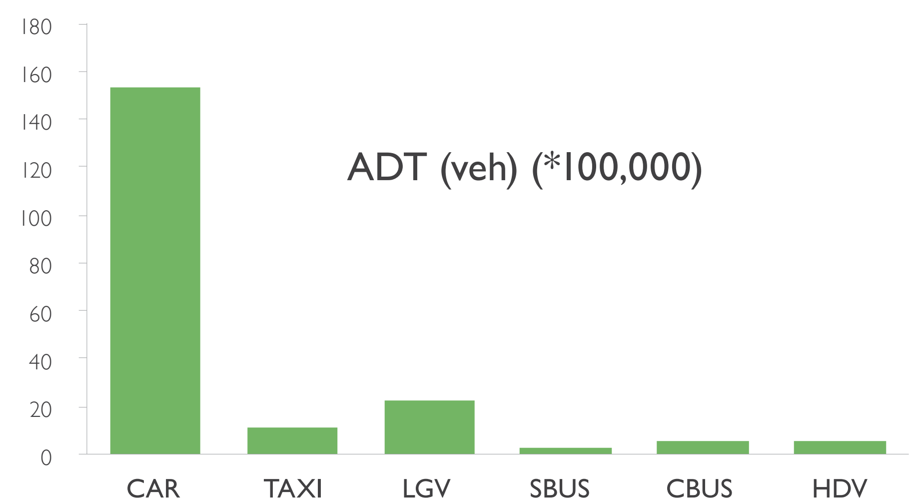
B. Road Classes

Road classes for Abu Dhabi Emirate were defined based on the embedded information in the road network. Around 60 road link types were provided and were aggregated in 6 road classes relevant for estimating air pollutant emissions, i.e. expressway, arterial, collector, local road, truck road and bus road.

C. Average Daily Traffic (ADT)

The average daily traffic (ADT) was provided by the Department of Transport (DoT), estimated using the STEAM model (Strategic Transportation Evaluation and Assessment Model). The traffic volumes are statistics provided for 2015, and they constitute the direct regional model outputs from the base year. For more detail information about the STEAM model, see Hibbert and O´Brien (2015).

The ADT is defined at the road link and it characterises the traffic flow at each road segment. The information was processed to facilitate the estimates of traffic emissions. For instance, the ADT at several road links were indicated to be 0 or very low. For estimating emissions in Abu Dhabi Emirate, it was decided to select all road links with ADT higher than 50. This application involves that 99.6 % of the annual traffic is taken into consideration. This assumption was benchmarked with different regions, and the lowest ADT considered was 100. Therefore our assumption can be considered a more complete approach.



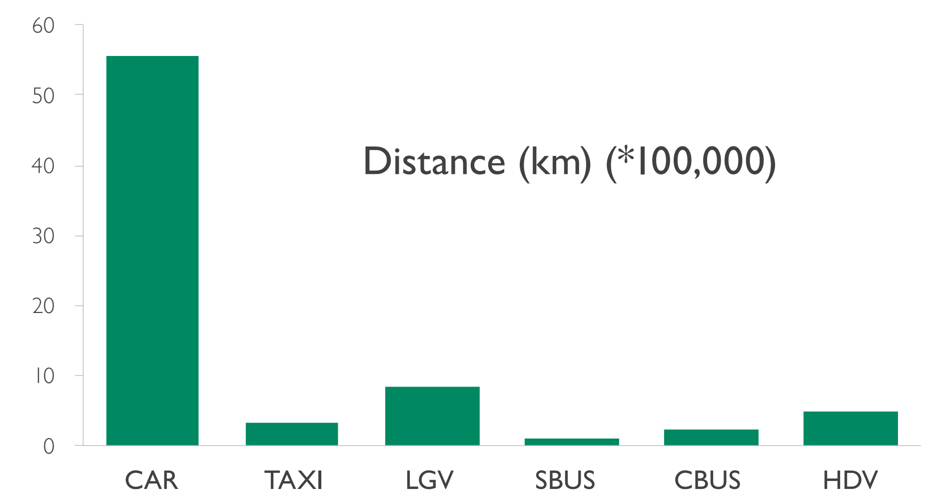


Figure 24: Total ADT for each vehicle class (top) and total driven distance (km; bottom).

D. Vehicle Class and Technology

The information about vehicle class and the corresponding ADT for each class was embedded in the road network at the road link level. The vehicle class classification included; 1) Car; 2) Taxi; 3) School Bus; 4) Company Bus; 5) Light Good Vehicle (LGV) and 6) Heavy Duty Vehicle (HDV). Figure 12 shows the total ADT as the sum of ADT for each vehicle class for all roads with ADT>50, and the distance as the total driven distance by all vehicles of that vehicle class, obtained by multiplying ADT with the length of the road segment. The most important vehicle class is cars, followed by LGV and HDV, pointing out at the potential weight of passenger cars in the total emissions from road transport.

The characteristics of the vehicle such as the type of fuel or the technology class are essential variables, as emissions will strongly depend on them. Information about the fleet composition in Abu Dhabi Emirate was provided by DoT and the original data source is Abu Dhabi Police. For the different vehicle classes, information about fuel type, weight of the vehicles, engine size, and emission standards was provided along with the share of each subtype. This information was used to select specific emission factors for each vehicle subcategory. Figure 25 shows a simplified overview of the fleet composition for the six vehicle technology classes and their emission standards. The technology class of each vehicle type is provided as emission standards following European and USA standards. The European emission standards are defined in a series of European Union Directives that establish the limits for exhaust emissions of vehicles sold in the European Union and European Economic Area member states. The series of directives state the introduction of increasing stringent emission limits. It is important to note that the vehicle emission standards adopted in Abu Dhabi Emirate reflect the GSO standards (Gulf Cooperation Council Standardization Organization) and additional information regarding sold vehicles with higher emission standards from distributors.

Table 30 shows as example the European emission standards for passenger cars and light commercial vehicles (≤1,305 kg). The emission standards differs per vehicle type, weight and fuel. For the emission standards for light commercial vehicles above 1,305 kg, trucks and buses, we refer to EMEP/EEA (2016) and Nesbit et al. (2016).

Table 30: European emission standards for passenger cars and light commercial vehicles (g/km). The information in brackets correspond to light commercial vehicles. The dates only apply to the release of the standards in Europe.

Tier	Date	NO_x	CO	PM
Diesel				
Euro 1	July 1992 (October 1994)	-	2.72	0.14
Euro 2	January 1996 (January 1998)	-	1.0	0.08
Euro 3	January 2000	0.50	0.66 (0.64)	0.05
Euro 4	January 2005	0.25	0.50	0.025
Euro 5a	September 2009	0.180	0.500	0.005
Euro 5b	September 2011	0.080 (0.180)	0.500	0.005
Euro 6	September 2014	0.080	0.500	0.005
Petrol				
Euro 1	July 1992 (October 1994)		2.72	
Euro 2	January 1996 (January 1998)		2.2	
Euro 3	January 2000	0.15	2.3	
Euro 4	January 2005	0.08	1.0	
Euro 5	September 2009	0.060	1.000	0.005
Euro 6	September 2014	0.060	1.000	0.005

The federal standards in the United States for light duty vehicles follow the pre-Tier 1, Tier 1, Tier 2 and Tier 2 standard. In this study, we assume stage 0, stage 1 and stage 2, as pre-tier 1, tier 1 and tier 2, respectively, based on communication with the DoT and EAD. For the specific information about emission limit for each vehicle category, we refer to https://www.dieselnet.com/standards/.

Passenger cars in Abu Dhabi Emirate are mostly classified as Euro 3 (Figure 13), which includes vehicles below and above 2.5t, and with different engine sizes (e.g. 1.4-2.0l and >2.0l). Euro 3 is followed by Euro 0 and Euro 2 with around 21 % and 7 % of the car fleet, respectively. Similarly, Taxis are mostly Euro 3 followed by Euro 0. The most important difference between passenger cars and taxis relates to the fuel. Whilst passenger cars run on petrol, taxis run on petrol, diesel and compressed natural gas (CNG). For instance, 71 % of the Euro 0 taxis run on petrol, followed by 24 % on CNG and only 5 % on diesel. A similar share is found for Euro 3 taxis, as 75 % run on petrol, 25 % on CNG and <1 % on diesel. School buses (SB) and company buses (CB) show similar characteristics, the latter one being older, as most of the SB are Euro 3 whereas the CB are Euro 2. The buses and HDV classified according to the European emission standards (e.g. Euro 0, Euro 1) are diesel vehicles, whereas those classified according to US EPA emission standards (e.g. Stage 0, Stage 1) are petrol vehicles.

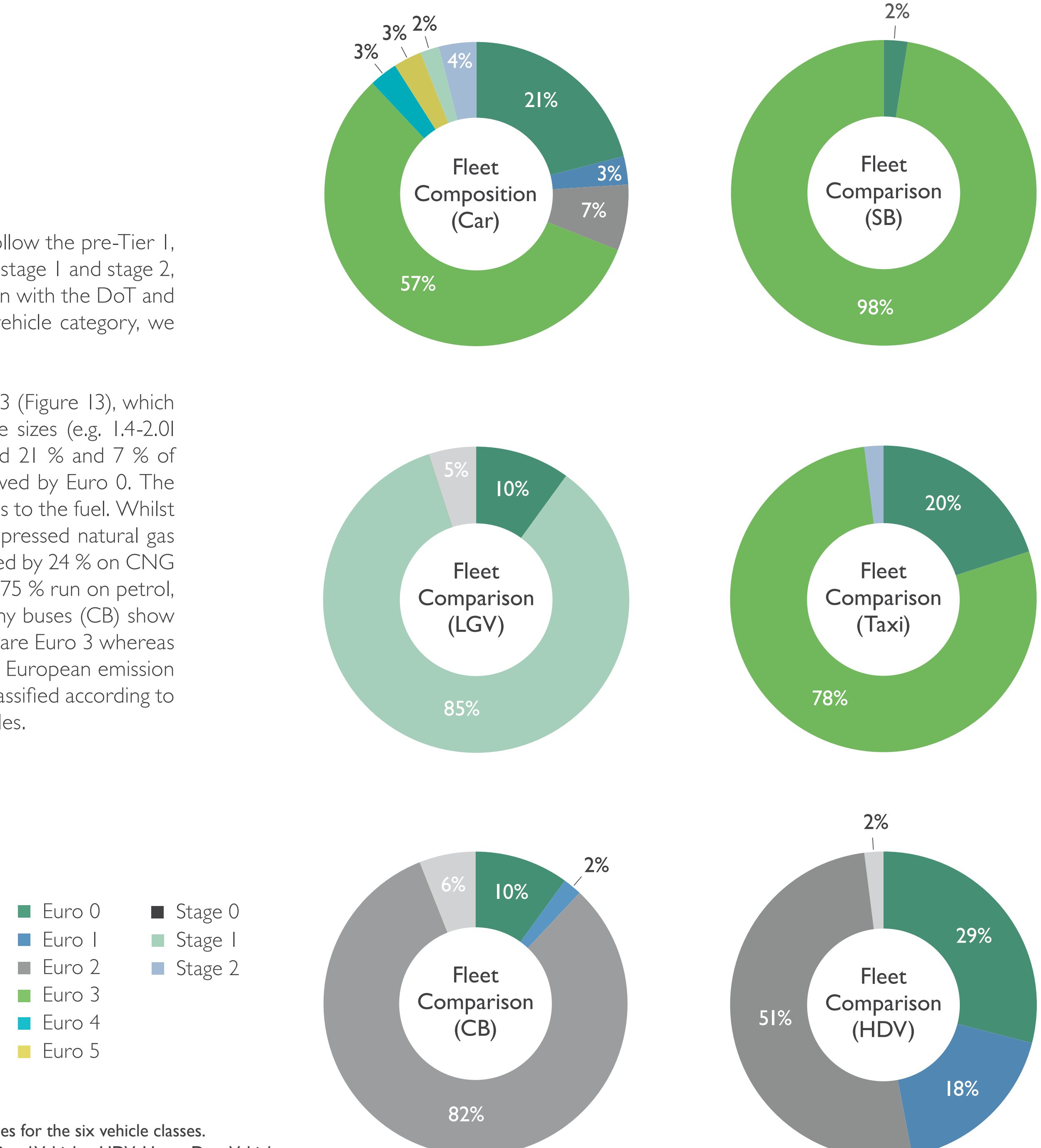


Figure 25: Overview of the vehicle technology classes for the six vehicle classes.
SB: School Buses, CB: Company Buses, LGV: Light Good Vehicles; HDV: Heavy Duty Vehicles.

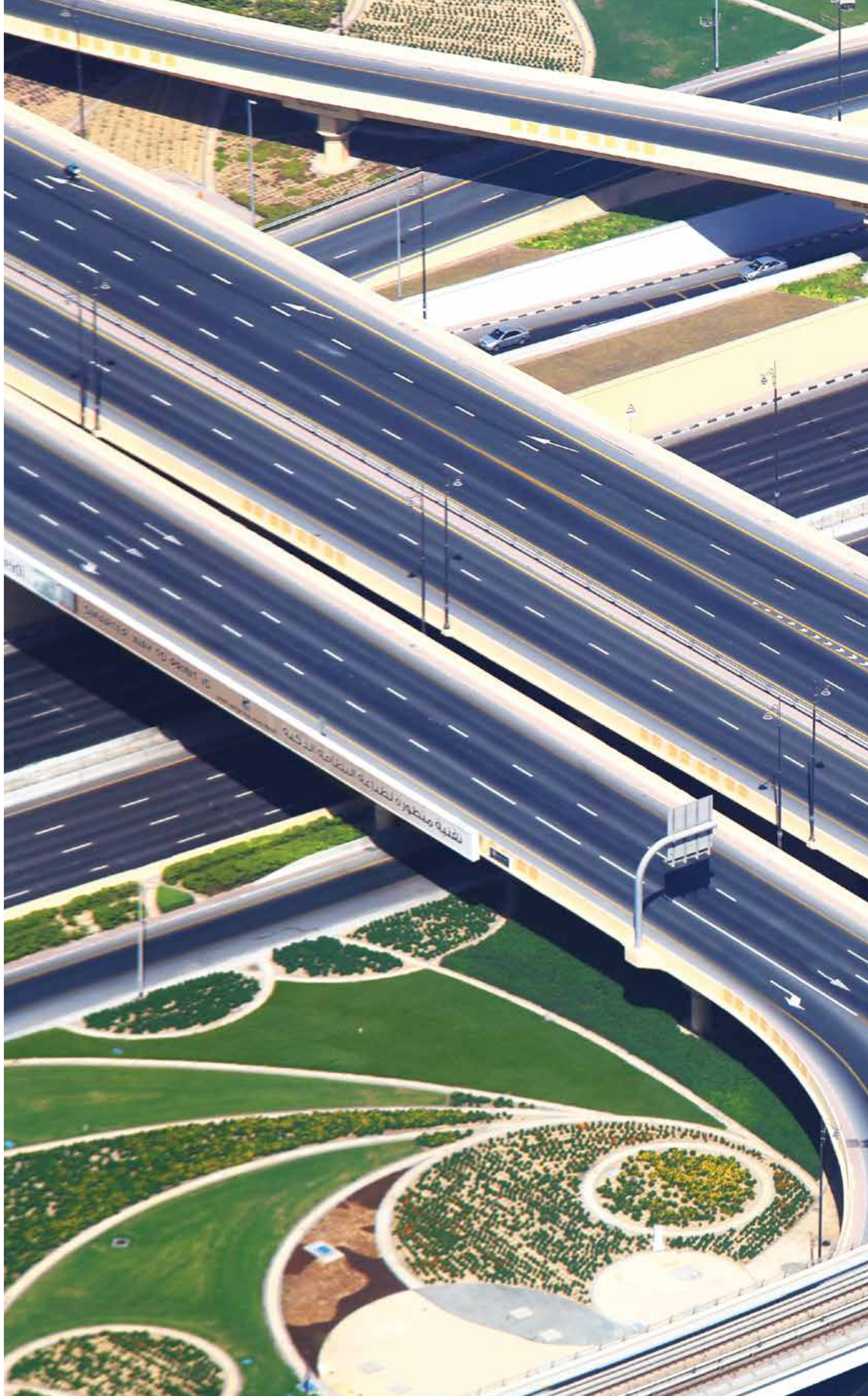
E. **Emission Factors**

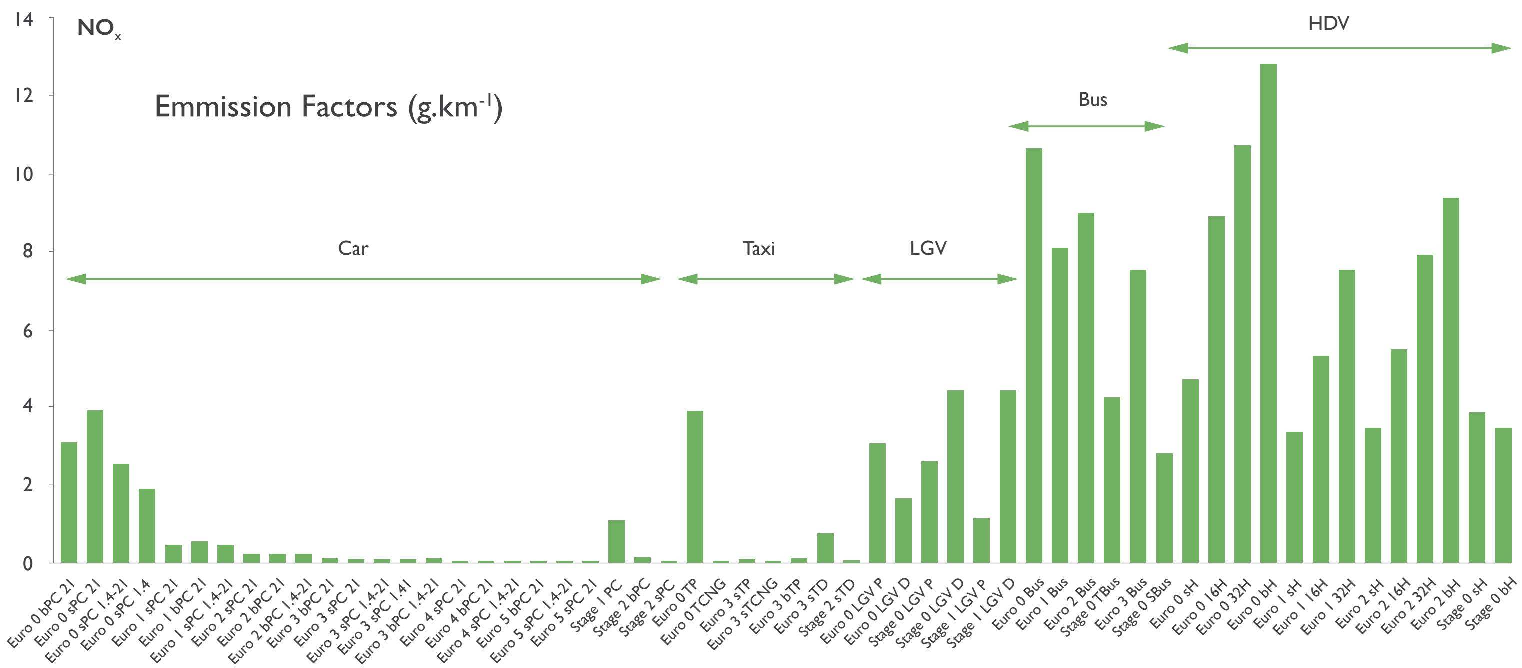
Emission factors (EF) were selected based on the vehicle weight, engine size and technology class expressed as emission standard (EMEP/EEA, 2016; US EPA, 2014). The EMEP/EEA (2016) guideline specifies that the emission factors can be applied in countries not following the Euro standards when information about correspondence between national technological classification and European classes is approximated, as it is the case of this study.

Emission factors for all pollutants and the share of each type of vehicle are shown in Table 31 to Table 36. These emission factors are basic factors that represent typical values for speed, ambient temperature, type of road mix, etc. The traffic emission model used in our study takes into account the basic emission factor and how it changes based on the ageing of the vehicle and the speed. Emission factors for vehicle technology classes defined according to European emission standards (e.g. Euro 0, Euro 1) are taken from EMEP/EEA (2016) guidelines, whereas those defined according to US standards (e.g. Stage 0, Stage 1) are taken from US EPA (2014). In the case of SO_2, emission factors were established based on the sulphur content in the fuel sold in Abu Dhabi Emirate, and emissions calculated assuming that all the sulphur in the fuel is transformed into SO_2. The sulphur content in the fuel was provided by EAD, and it corresponds to 100 ppm and 10 ppm for petrol and diesel, respectively, whereas for CNG it is assumed to be 0 ppm. To estimate EFSO2, we considered typical fuel consumption figures per type of vehicle (EMEP/EEA, 2016).

Figure 14 shows the NO_X and CO emissions factors for the vehicle fleet composition of Abu Dhabi Emirate as an example. It is noteworthy to highlight that buses and heavy duty vehicles (HDV) are the main contributors to NO_X emissions. The reason relates to the fuel, since both buses and HDV run mostly on diesel, whilst 100 % of the passenger cars in Abu Dhabi Emirate run on petrol. The opposite pattern is observed for CO emission factors. Passenger cars, few buses and few HDV run on petrol, and they constitute the main contributors to CO emissions per kilometre.

Apart from the differences determined by the type of fuel, emission units per kilometre depend on the technology class or emission standard of the vehicles. Hereby, NO_X emissions per kilometre for Euro 0 passenger cars are 4 times higher than emissions from Euro 1, and the difference becomes higher when comparing with Euro 2 and Euro 3. These differences are similarly observed for other compounds (Figure 14, from Table 31 to Table 36).





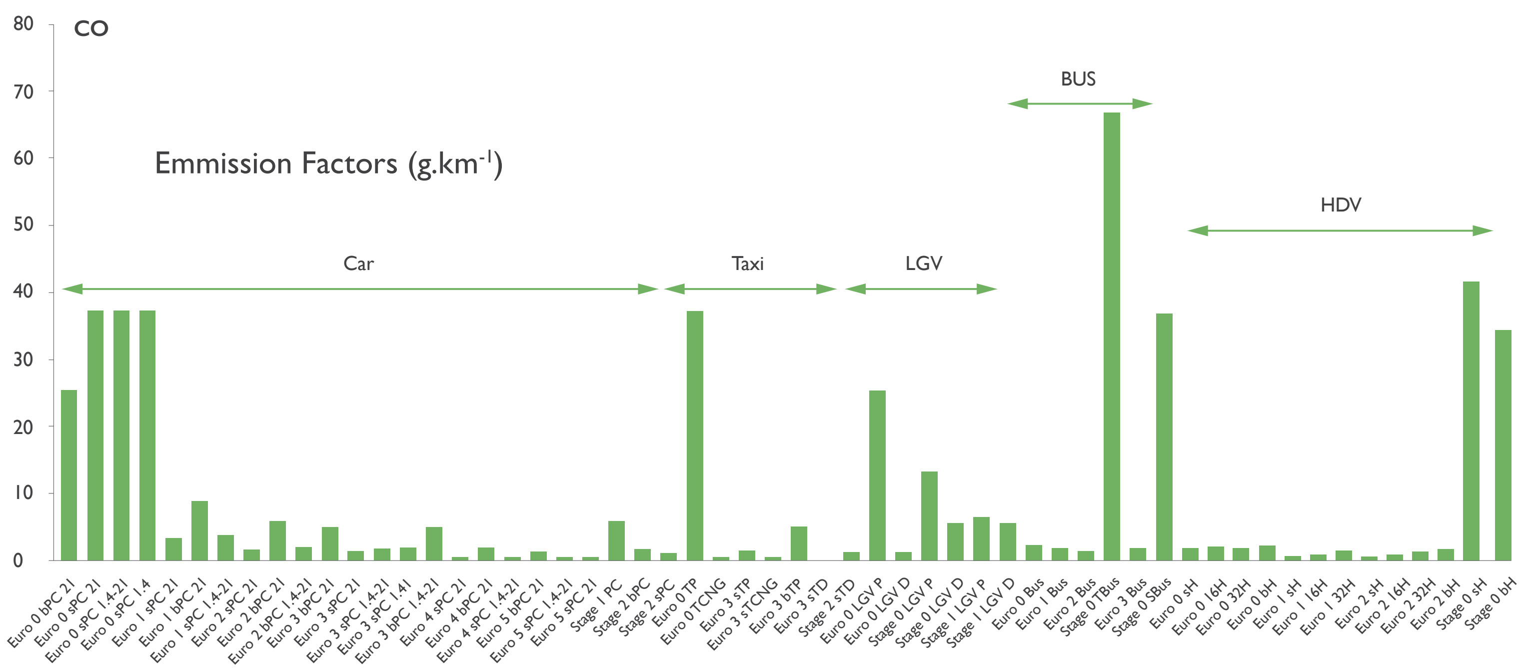


Figure 26: Emission factors for NO_x and CO for the different vehicle technology classes and emission standards (e.g. Euro 0, Euro 1, Euro 2, Euro 3) based on EMEP/EEA (2016) and input data in the traffic emission model. P: petrol, D: diesel, b: big size vehicle (e.g. >2.5t for cars, >32t for heavy vehicles), s: small size vehicle (e.g. <2.5t for cars, ≤7.5t for heavy vehicles).

Table 31: Emission factors for passenger cars and the corresponding for the different types of vehicles. Prefers to petrol. Source EMEP/EEA (2016), US EPA (2014). Share (%) represents the percentage of cars in each category.

Fuel	Weight (t)	Engine Size (l)	Emission Standard	Share (%)	CO (g/km)	NMVOC (g/km)	NO_x (g/km)	PM (g/km)	SO_2 (g/km)
P	>2.5	>2.0	Euro 3	24	5.05	0.19	0.13	0.001	0.014
P	<2.5	>2.0	Euro 3	21	1.50	0.09	0.09	0.001	0.014
P	<2.5	1.4-2.0	Euro 3	10	1.82	0.12	0.10	0.001	0.014
P	>2.5	>2.0	Euro 0	9	25.50	3.44	3.09	0.002	0.014
P	<2.5	>2.0	Euro 0	8	37.30	2.77	3.90	0.002	0.014
P	<2.5	>2.0	Euro 2	4	1.67	0.20	0.24	0.002	0.014
P	<2.5	1.4-2.0	Euro 0	3	37.30	2.80	2.53	0.002	0.014
P	>2.5	>2.0	Stage 2	2	1.75	0.02	0.16	0.003	0.014
P	<2.5	>2.0	Stage 2	2	1.22	0.01	0.07	0.002	0.014
P	>2.5	>2.0	Euro 2	2	5.89	0.30	0.23	0.002	0.014
P	>2.5	>2.0	Stage 1	2	6.02	0.31	1.11	0.010	0.014
P	<2.5	>2.0	Euro 4	1	0.53	0.05	0.06	0.001	0.014
P	<2.5	<1.4	Euro 3	1	2.07	0.09	0.09	0.001	0.014
P	>2.5	>2.0	Euro 4	1	2.01	0.13	0.06	0.001	0.014
P	>2.5	>2.0	Euro 5	1	1.30	0.10	0.06	0.001	0.014
P	<2.5	>2.0	Euro 1	1	3.41	0.43	0.47	0.002	0.014
P	<2.5	1.4-2.0	Euro 2	1	2.04	0.25	0.26	0.002	0.014
P	<2.5	1.4-2.0	Euro 5	1	0.62	0.07	0.06	0.001	0.014
P	>2.5	>2.0	Euro 1	1	8.82	0.61	0.56	0.002	0.014
P	<2.5	>2.0	Euro 5	1	0.53	0.05	0.06	0.001	0.014
P	>2.5	1.4-2.0	Euro 3	1	5.05	0.19	0.13	0.001	0.014
P	<2.5	<1.4	Euro 0	1	37.30	2.77	1.91	0.002	0.014
P	<2.5	1.4-2.0	Euro 1	1	3.92	0.53	0.49	0.002	0.014
P	<2.5	1.4-2.0	Euro 4	1	0.62	0.07	0.06	0.001	0.014

Table 32: Emission factors for the different types of taxis and the corresponding share. P: petrol; D: diesel; CNG: Compressed Natural Gas. Source EMEP/EEA (2016), US EPA (2014). Share (%) represents the percentage of taxis in each category.

Fuel	Weight (t)	Engine Size (l)	Emission Standard	Share (%)	CO (g/km)	NMVOC (g/km)	NO_x (g/km)	PM (g/km)	SO_2 (g/km)
P	<2.5	>2.0	Euro 3	56	1.50	0.09	0.09	0.001	0.014
CNG	<2.5	>2.0	Euro 3	18	0.62	0.04	0.06	0.001	0.000
P	<2.5	>2.0	Euro 0	15	37.30	2.77	3.90	0.002	0.014
CNG	<2.5	>2.0	Euro 0	5	0.62	0.04	0.06	0.001	0.000
P	>2.5	>2.0	Euro 3	3	5.05	0.19	0.13	0.001	0.014
P	<2.5	>2.0	Stage 2	2	1.22	0.01	0.07	0.002	0.014
D	<2.5	>2.0	Euro 3	1	0.09	0.04	0.77	0.039	0.0012

Table 33: Emission factors for the different types of light good vehicles (LGV) and the corresponding share. P: petrol; D: diesel. Source EMEP/EEA (2016), US EPA (2014). Share (%) represents the percentage of LGV in each category.

Fuel	Weight (t)	Engine Size (l)	Emission Standard	Share (%)	CO (g/km)	NMVOC (g/km)	NO_x (g/km)	PM (g/km)	SO_2 (g/km)
P	1305-1760	ALL	Stage 1	36	6.58	0.36	1.15	0.011	0.02
P	1760-3500	ALL	Stage 1	24	6.58	0.36	1.15	0.011	0.02
D	1760-3500	ALL	Stage 1	17	5.63	0.95	4.44	0.214	0.0016
D	1305-1760	ALL	Stage 1	8	5.63	0.95	4.44	0.214	0.0016
P	1305-1760	ALL	Euro 0	4	25.50	3.44	3.09	0.002	0.02
P	1760-3500	ALL	Euro 0	3	25.50	3.44	3.09	0.002	0.02
P	1305-1760	ALL	Stage 0	2	13.30	0.81	2.63	0.017	0.02
D	1760-3500	ALL	Euro 0	2	1.34	0.13	1.66	0.356	0.0016
D	1760-3500	ALL	Stage 0	2	5.63	0.95	4.44	0.214	0.0016
P	1760-3500	ALL	Stage 0	1	13.30	0.81	2.63	0.017	0.02
D	1305-1760	ALL	Euro 0	1	1.34	0.13	1.66	0.356	0.0016

Table 34: Emission factors for the different types of School Buses (SB) and the corresponding share. P: petrol; D: diesel. Source EMEP/EEA (2016), US EPA (2014). Share (%) represents the percentage of SB in each category.

Fuel	Weight (t)	Engine Size (l)	Emission Standard	Share (%)	CO (g/km)	NMVOC (g/km)	NO_x (g/km)	PM (g/km)	SO_2 (g/km)
D	15-18	ALL	Euro 3	49	1.91	0.399	7.51	0.178	0.0048
D	≤15	ALL	Euro 3	48	1.91	0.399	7.51	0.178	0.0048
P	≤15	ALL	Stage 0	2	36.86	1.17	2.80	0.034	0.06
P	15-18	ALL	Stage 0	0.5	36.86	1.17	2.80	0.034	0.06
D	>18	ALL	Euro 3	0.5	1.91	0.399	7.51	0.178	0.0048

Table 35: Emission factors for the different types of Company Buses (CB) and the corresponding share. P: petrol; D: diesel. Source EMEP/EEA (2016), US EPA (2014). Share (%) represents the percentage of CB in each category.

Fuel	Weight (t)	Engine Size (l)	Emission Standard	Share (%)	CO (g/km)	NMVOC (g/km)	NO_x (g/km)	PM (g/km)	SO_2 (g/km)
D	≤15	ALL	Euro 2	44	1.60	0.42	8.95	0.165	0.0048
D	15-18	ALL	Euro 2	38	1.60	0.42	8.95	0.165	0.0048
D	≤15	ALL	Euro 0	5	2.27	0.66	10.60	0.470	0.0048
D	15-18	ALL	Euro 0	5	2.27	0.66	10.60	0.470	0.0048
P	≤15	ALL	Stage 0	5	66.72	1.65	4.23	0.081	0.06
P	15-18	ALL	Stage 0	1	66.72	1.65	4.23	0.081	0.06
D	≤15	ALL	Euro 1	1	1.85	0.62	8.10	0.362	0.0048
D	15-18	ALL	Euro 1	1	1.85	0.62	8.10	0.362	0.0048

Table 36: Emission factors for the different types of Heavy Duty Vehicles (HDV) and the corresponding share. P: petrol; D: diesel. Source EMEP/EEA (2016), US EPA (2014). Share (%) represents the percentage of HDV in each category.

Fuel	Weight (t)	Engine Size (l)	Emission Standard	Share (%)	CO (g/km)	NMVOC (g/km)	NO_x (g/km)	PM (g/km)	SO_2 (g/km)
D	≤7.5	ALL	Euro 0	11	1.85	1.07	4.70	0.333	0.0048
D	28-34	ALL	Euro 2	11	1.38	0.29	7.91	0.155	0.0048
D	≤7.5	ALL	Euro 2	10	0.54	0.12	3.49	0.061	0.0048
D	14-20	ALL	Euro 2	9	0.90	0.21	5.50	0.104	0.0048
D	20-28	ALL	Euro 2	8	1.38	0.29	7.91	0.155	0.0048
D	14-20	ALL	Euro 0	7	2.13	0.78	8.92	0.334	0.0048
D	≤7.5	ALL	Euro 1	6	0.66	0.19	3.37	0.129	0.0048
D	14-20	ALL	Euro 1	5	1.02	0.33	5.31	0.201	0.0048
D	7.5-12	ALL	Euro 2	5	0.90	0.21	5.50	0.104	0.0048
D	20-28	ALL	Euro 0	4	1.93	0.49	10.70	0.418	0.0048
D	20-28	ALL	Euro 1	4	1.55	0.45	7.52	0.297	0.0048
D	14-20	ALL	Euro 2	3	0.90	0.21	5.50	0.104	0.0048
D	7.5-12	ALL	Euro 0	2	2.13	0.78	8.92	0.334	0.0048
D	28-34	ALL	Euro 0	2	1.93	0.49	10.70	0.418	0.0048
P	≤7.5	ALL	Stage 0	1	41.81	1.36	3.83	0.035	0.06
D	14-20	ALL	Euro 0	1	2.13	0.78	8.92	0.334	0.0048
D	28-34	ALL	Euro 1	1	1.55	0.45	7.52	0.297	0.0048
D	20-26	ALL	Euro 2	1	1.38	0.29	7.91	0.155	0.0048
D	7.5-12	ALL	Euro 1	1	1.02	0.33	5.31	0.201	0.0048
D	>32	ALL	Euro 2	1	1.69	0.33	9.36	0.194	0.0048
D	14-20	ALL	Euro 1	1	1.02	0.33	5.31	0.201	0.0048
D	12-14	ALL	Euro 2	1	0.90	0.21	5.50	0.104	0.0048
D	50-60	ALL	Euro 2	1	1.69	0.33	9.36	0.194	0.0048
D	28-32	ALL	Euro 2	1	1.38	0.29	7.91	0.155	0.0048
P	14-20	ALL	Stage 0	1	34.39	1.25	3.50	0.031	0.06
D	>32	ALL	Euro 0	1	2.25	0.53	12.80	0.491	0.0048
D	12-14	ALL	Euro 0	1	2.13	0.78	8.92	0.334	0.0048

F. Mileage

One of the parameters considered when estimated traffic emissions is the annual average driving distance or mileage. This parameter affects the ageing factor that defines how emissions change with time (i.e. with use of the vehicle). A previous traffic emission inventory carried out in Abu Dhabi established, based on personal communication with AXA Insurance Company, that the average mileage for passenger cars varies between 15,000 and 40,000 km, and for heavy goods vehicles (trucks) operating within the UAE between 120,000 and 180,000 km. For the 2015 traffic emission inventory, mileages have been kept within these limits for the various classes of vehicles (Table 37). We assume that the mileage of taxis is above passenger cars, and the mileage of LGV is below that for HDV. Moreover, it is assumed that older cars travel slightly less than relatively new cars.

Table 37: Annual average driving distance.

Vehicle Class	Emission Standard	Mileage (km/yr)
Car	Euro 0	15,000
Car	Euro 1	17,000
Car	Euro 2	19,000
Car	Euro 3	21,000
Car	Euro 4	23,000
Car	Euro 5	25,000
Car	Stage 1	17,000
Car	Stage 2	19,000
Taxi	Euro 0	50,000
Taxi	Euro 3	50,000
Taxi	Stage 2	50,000
LGV	Euro 0	70,000
LGV	Stage 0	70,000
LGV	Stage 1	70,000
SB/CB	Euro 0	70,000
SB/CB	Euro 1	80,000
SB/CB	Euro 2	90,000
SB/CB	Stage 0	70,000
SB/CB	Euro 3	10,000
SB/CB	Stage 0	70,000
HDV	Euro 0 sH	70,000
HDV	Euro 0 16H	80,000
HDV	Euro 0 32H	80,000
HDV	Euro 0 bH	100,000
HDV	Euro 1 sH	80,000
HDV	Euro 1 16H	90,000
HDV	Euro 1 32H	100,000
HDV	Euro 2 sH	90,000
HDV	Euro 2 16H	100,000
HDV	Euro 2 32H	100,000
HDV	Euro 2 bH	120,000
HDV	Stage 0 sH	70,000
HDV	Stage 0 bH	80,000

G. Ageing Factor

The effectiveness of emission control technologies decreases with time due to different factors such as use, mechanical usages, wearing of catalyst, among others. Consequently, vehicles with catalyst do not maintain their basic emission factors over their lifetime. The ageing factors considered in our study to represent the degradation, are from an internal database that reflects that different vehicles types and components will be affected by aging in different ways. For NO_x and CO emissions, we consider an accumulated distance of 120,000 km as a limit from where emissions do not further degrade (EMEP/EEA, 2016).

H. Speed Dependent Factor

One of the factors affecting emissions is the vehicle speed, and exhaust emissions tend to decrease as the speed goes up to around 80-100 km/h, but thereafter the trend is reversed at higher speeds. This relationship is reported to be due to the increased load on the engine and changes in efficiency when the engine operates at a different operating condition (i.e. engine speed range). The effects of speed are sometimes more apparent on the latest generation of vehicles with after-treatment devices. The reason is that vehicles undergo a mild driving cycle when they are tested during approval procedure. The manufacturers may calibrate the engine to be "clean" within a narrow operating range, but then revert to a high emission mode for maximum power to satisfy the driver's expectations. We use the speed dependency factors available in in-house databases and previously used in other applications. Figure 15 shows as an example the speed dependency factors for CO, NO_x and NMVOC for passenger cars with Euro 1 emission standards and heavy-duty vehicles with Euro 2 emission standard.

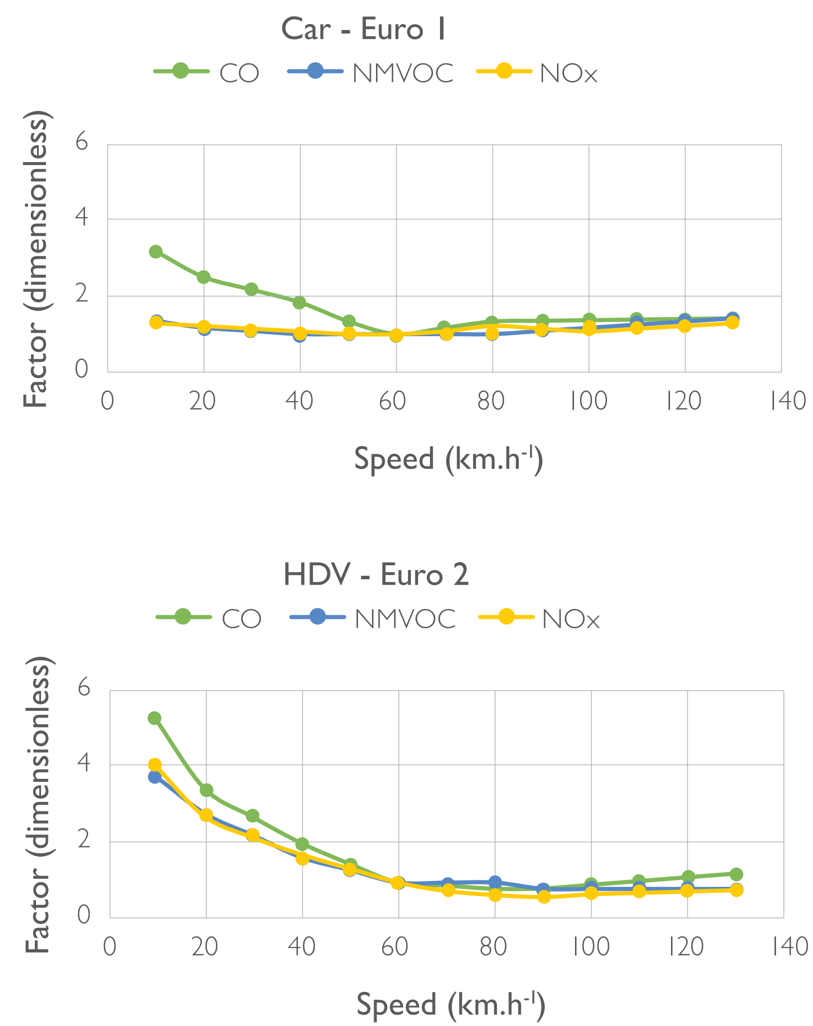


Figure 27: Speed dependency factors for Car – Euro 1 and HDV – Euro 2.

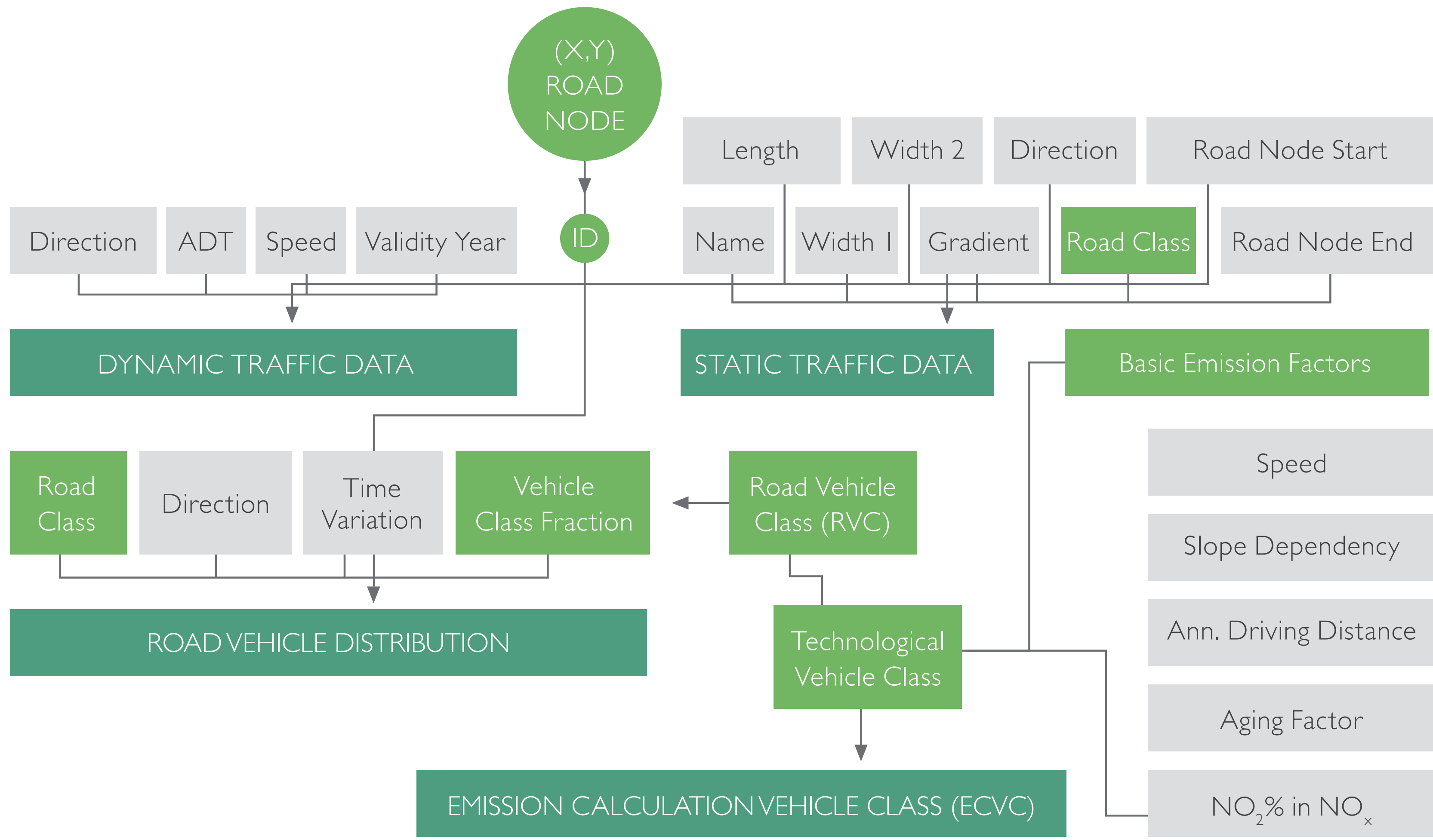


Figure 28: Schematic diagram of the bottom-up approach used to estimate emissions for each road link

6.2 **Emissions from Road Transport Sector**

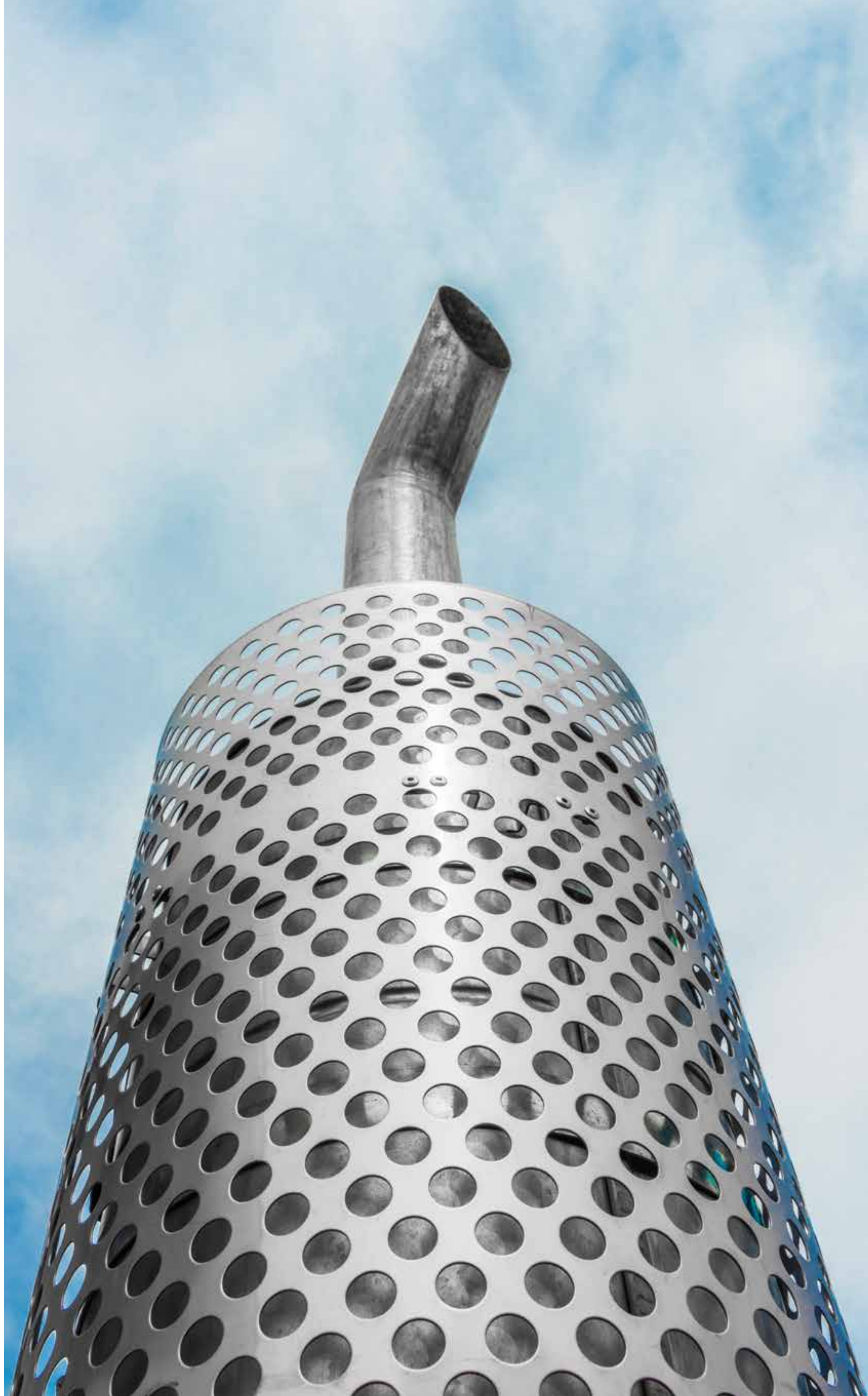
Figure 16 and Table 38 show emissions from NO_X, SO_2, CO, PM and NMVOC from road transport. Traffic is an important contributor to CO emissions, because of the high share of old vehicles running with petrol, and specially passenger cars contributing by around 80 % to total traffic emissions of CO.

NO_X and NMVOC emissions are at similar levels, the first one associated with passenger cars and specially HDV running on diesel, whereas the latter one, NMVOC, is associated with petrol passenger cars.

Total emissions of SO_2 and PM are 399 and 1,464 tonnes per year. SO_2 emissions are associated with the sulphur content in the fuels, namely, 100 ppm and 10 ppm for petrol and diesel respectively.

Table 38: Emissions from traffic (t/yr) in Abu Dhabi Emirate in the year 2015.
PM refers to exhaust PM emissions and we assume $PM_{2.5}$=PM_{10}.

	NO_X (t/yr)	SO_2 (t/yr)	CO (t/yr)	PM (t/yr)	NMVOC (t/yr)
CAR	17,518	315	362,054	63	26,905
TAXI	570	13	15,412	5	1,828
LGV	6,200	51	48,968	424	5,260
SBUS	1,733	2	1,384	103	100
CBUS	3,326	6	7,196	199	458
HDV	6,670	12	6,042	670	327
TOTAL	36,017	399	441,056	1,464	34,878



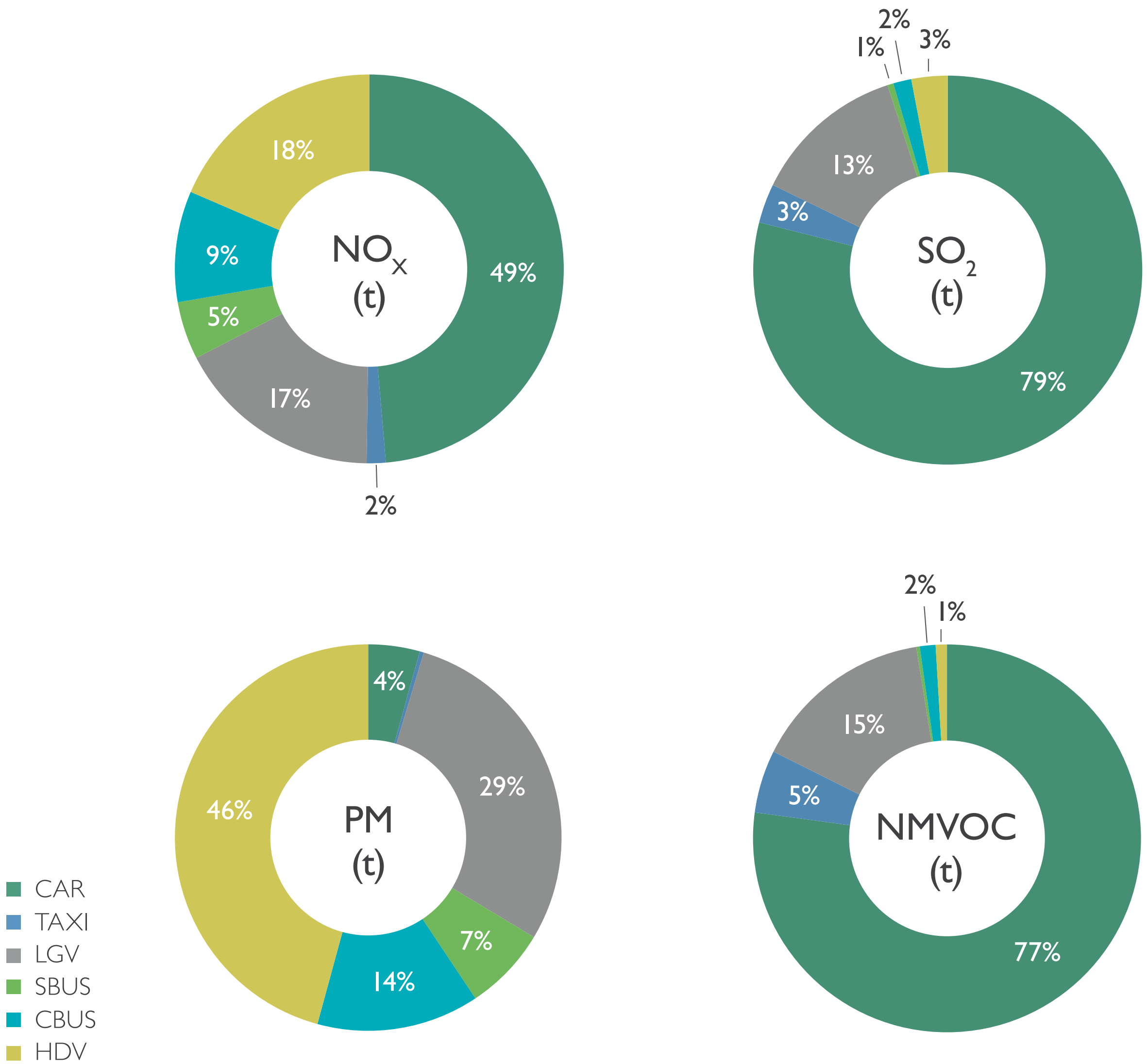


Figure 29: Emissions of NO_x, SO_2, CO, NMVOC and PM per vehicle class in Abu Dhabi Emirate.

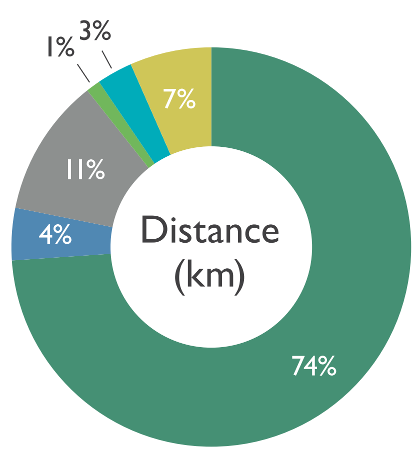
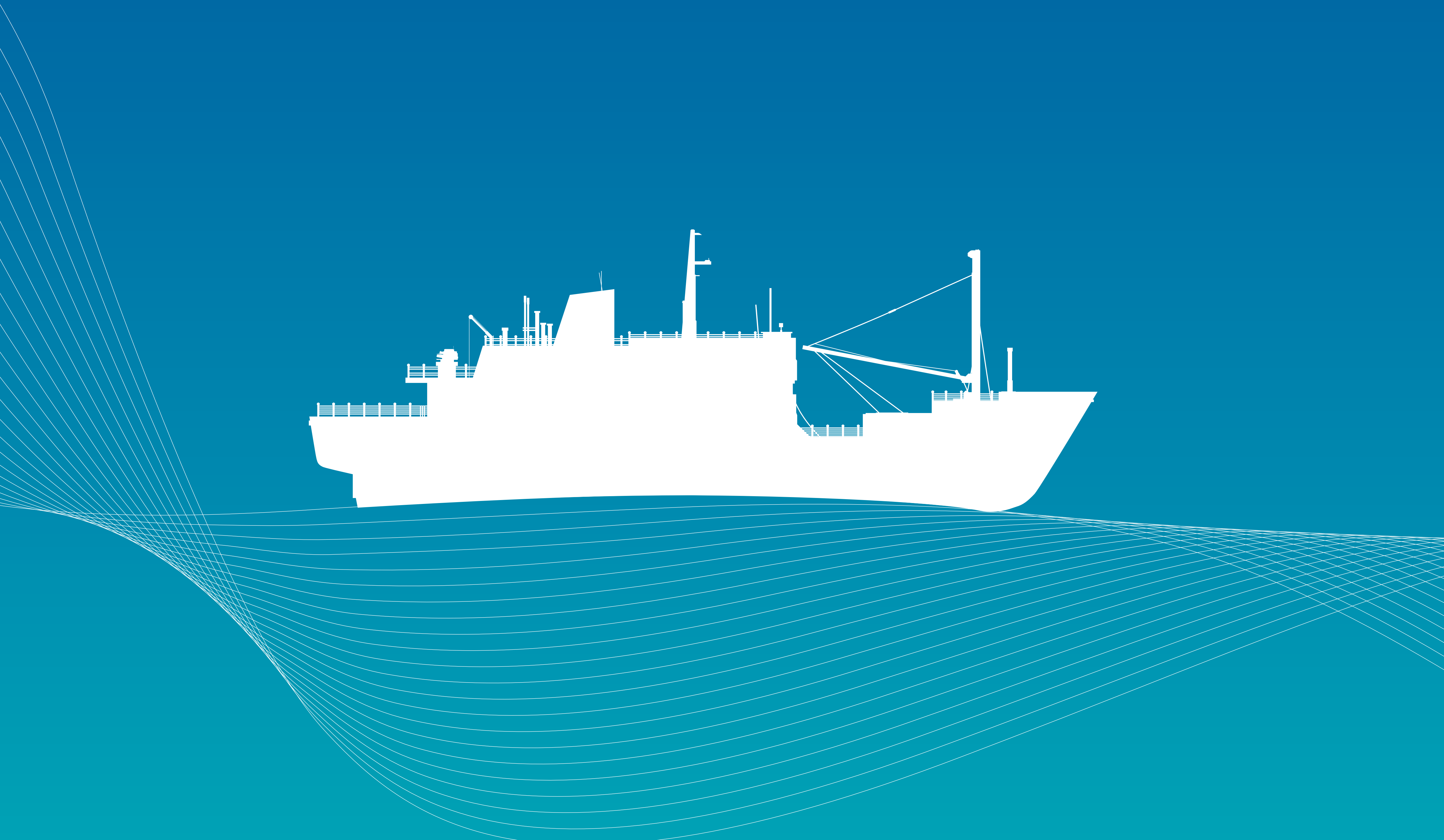


Figure 30: Distance travelled by each vehicle class.



Shipping Sector

7 Shipping Sector

The shipping sector includes the activities in the Abu Dhabi Ports Company (Zayed, Khalifa and Musaffah), which operates all commercial, logistics, community and leisure ports in Abu Dhabi Emirate. Zayed Port is a commercial port with a well-equipped container terminal that was established back in 1982. Zayed Port is an important gateway for international trade in the emirate. In 2012, the container traffic was transferred from Zayed to Khalifa Port that handles the entire emirate's container traffic. Musaffah Port is located in the industrial area of Musaffah, and it includes a general cargo terminal, as well as an extensive waterfront for private berths and terminals. It is noteworthy to highlight that the emissions from the shipping sector in the inventory only represent those occurring within the ports water limit.

7.1 Method to estimate Shipping Emissions

Emissions associated with shipping activities at the ports in Abu Dhabi Emirate are estimated based on the method suggested by US EPA (2009), combined with the recommendations from EMEP/EEA (2016) and the method employed in the development of a bottom-up emission inventory for the Port of Oslo (López-Aparicio et al., 2017). The focus of this study is on shipping emissions that occur at the port area by oceangoing vessels (OGV) and harbour vessels (HV). We define OGV as the vessels that arrive and operate in the port area and thereafter travel to open sea (e.g. containers vessels), whereas HV are defined as those that operate the whole year round within the port area. In this inventory, emissions from OGV during three different operation modes have been included, i.e. arriving/departing from the port, during manoeuvring and at berth. Emissions from OGVs are estimated based on the activity in the different ports, whereas those from HVs are estimated based on the fuel consumption reported by Abu Dhabi Ports. The contribution from HVs to total shipping emissions is much lower than from OGV, being estimated to be around 5 and 95 %, respectively. These results are in agreement with previous studies, i.e. a bottom-up emission inventory carried out for the Port of Oslo which showed that the contribution from OGV to total NO_X emissions from the port was 78 % whereas harbour vessels contribute to 14 % (Lopez-Aparicio et al., 2017).

We estimate emissions from OGVs, and per operational modes, according to the following expressions:

$$E_{i,\text{“cru”}} = \sum EF_{i,j\text{“cru”}} \times LF_{j,\text{“cru”}} \times t_{j,\text{“at cru”}} \times HP_j \qquad \textit{Equation 7}$$

$$E_{i,\text{“man”}} = \sum EF_{i,j\text{“man”}} \times LF_{j\text{“cru”}} \times t_{j\text{“man”}} \times HP_j \qquad \textit{Equation 8}$$

$$E_{i,\text{“ber”}} = \sum EF_{i,j\text{“ber”}} \times LF_{j\text{“ber”}} \times t_{j\text{“ber”}} \times HP_j \qquad \textit{Equation 9}$$

Where Ei refers to emissions of pollutant i from OGV while arriving/departing from the port (“cru”), manoeuvring (“man”) and when at berth (“ber”). EFi,j refers to the emission factors (g/kWh) for the pollutant i and the OGV type j, under the three operational modes, and tj refers to the average time (h) employed by each OGV type j in the three different operational modes. LFj refers to the load factor of each OGV type j, and HP refers to the horsepower of each OGV type j (kW). The average horsepower for main engine and auxiliary engine used is according to EMEP/EEA (2016) per type of vessel, the latter one based on the recommended average vessel horsepower ratio for a 2010 world fleet. Likewise, the source of the load factor (LF) for both main and auxiliary engines of different types of vessels and under different operational modes is EMEP/EEA (2016). The EF for NO_X, PM, SO_2 and CO_2, for the different types of vessels, and under different operation modes are taken from ENTEC (2002) for territorial waters different from emission control areas (ECA). In the absence of emission factors for CO and NMVOC, the following assumptions have been made; EF_{CO} is obtained from EMEP/EEA (2016) considering a Tier 1 level along with the ratio EF_{NOX} to EF_{CO}. The EF_{NMVOC} are derived as 98 % of the original EF for hydrocarbons (HC) based on reported factors for methane from IPCC (1997), following the European guideline on emission inventories (EMEP/EEA, 2016). Table 39 shows an overview of the source of the input data used in the emission estimates of shipping from Abu Dhabi Ports.

Table 39: Overview of the source of input data considered for the estimates of emissions from shipping at Abu Dhabi ports.

Type of vessels	Input Data	Resolution	Source
OGV	EF; NO_x, PM, SO_2, CO, NMVOC, CO_2, (g/kWh)	Type of vessels; operational mode	ENTEC 2002, EMEP/EEA (2016), IPCC (1997)
	Load factors (LF; dimensionless)	Type of vessels; type of engine; operational mode	EMEP/EEA (2016)
	Horsepower (kW)	Type of vessel; type of engine	EMEP/EEA (2016)
	Time (h) at operational mode	Type of vessel	Abu Dhabi Ports
HV	Fuel consumption	Type of vessel	Abu Dhabi Ports
	EF: NO_x, PM, SO_2, CO, NMVOC, CO_2, (g/kWh) and specific fuel consumption (g fuel/kWh)	Type of vessel	ENTEC 2002, EMEP/EEA (2016), US EPA (2009)

The number of the different types of vessels (Figure 31), and the average time spent by each type of vessels in the different operational modes is provided by Abu Dhabi Ports Company. The data is collected as average turnaround, average manoeuvring and average hoteling. During evaluation of the input data provided, we identified certain inconsistencies. After communication between EAD and Abu Dhabi Ports, it was decided to use the manoeuvring time recommended by EMEP/EEA (2016).

The emissions from harbour vessels are estimated based on the fuel consumption reported by Abu Dhabi Ports and emissions factors (Table 41 and Table 40). This approach was selected over a method based on activity data (Annual operating time) as in the latter one the number of assumptions is higher and could, therefore, result in higher uncertainties.

Table 40: Emission factors for harbour vessels (ENTEC, 2002, EMEP/EEA, 2016, US EPA, 2009).

	EF (g/kWh)					
	NO_x	NMVOC	PM	CO	SO_2	CO_2
Tug	6.8	0.27	0.3	5	4	690
Landing Craft	8.6	1.97	1.2	5	4	690
Pilot Launch	8.6	1.97	1.2	5	4	690
Speed boat	12	9	0.08	5	4	690

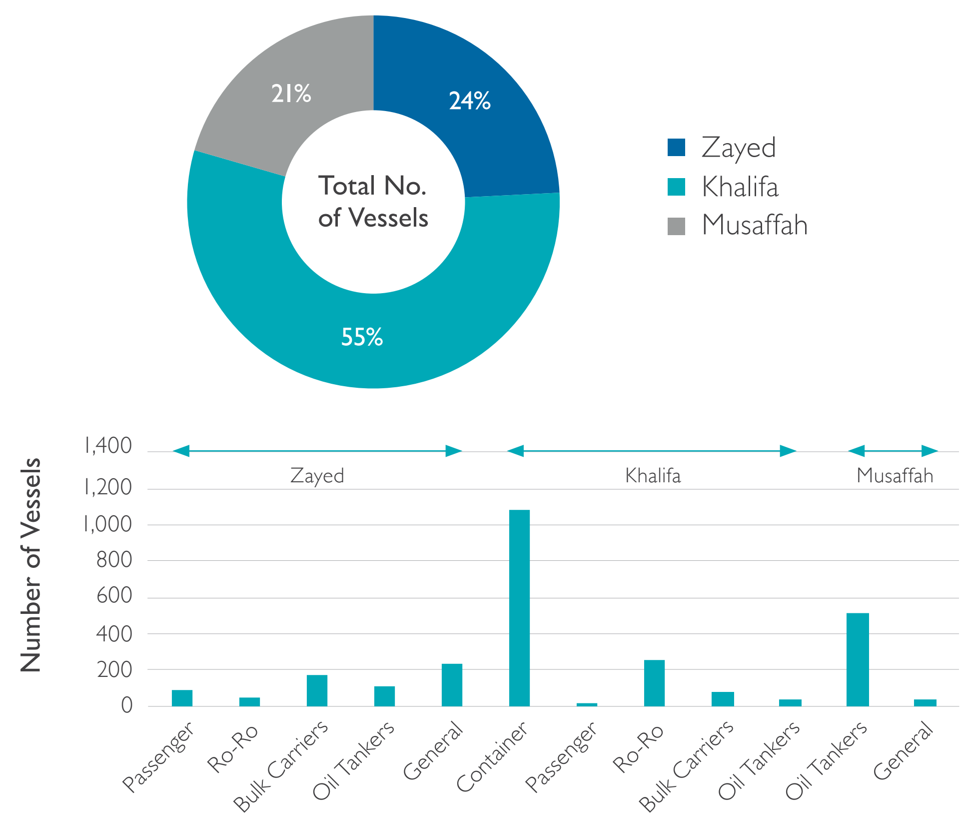


Figure 31: Number of vessels by type and port.

7.2 Emissions from Shipping Sector

Table 41 and Figure 32 show emissions of criteria pollutants and CO_2 from different Abu Dhabi Port distributed between OGV and HV. The highest emissions are estimated for Khalifa Port, with 68 % and 56 % contribution to total shipping emissions of NO_X and SO_2 (Figure 32), respectively, followed by Musaffah (20 % NO_X contribution and 31 % SO_2 contribution), and Zayed. The magnitude of the emissions is associated with the activity of the port. According to the data provided by Abu Dhabi Ports Company for the year 2015, Khalifa port had 1,470 calls from OGV, most of them containers, versus 546 calls at Musaffah consisting of oil tankers (512 calls) and general cargo (34 calls). Harbour vessels have a very small contribution to total shipping emissions (Table 41).

Table 41: Emissions (t/yr) from shipping (Oceangoing vessels and Harbour vessels) in Abu Dhabi Ports in 2015. The harbour vessels in Musaffah are covered by Zayed. PM refers to PM_{10} and $PM_{2.5}$, as it is assumed that $PM_{10} = PM_{2.5}$.

	Emissions from shipping in Abu Dhabi Emirate, 2015					
	NO_X (t/yr)	PM (t/yr)	CO (t/yr)	SO_2 (t/yr)	NMVOC (t/yr)	CO_2 (t/yr)
OCEANGOING VESSELS (OGV)						
Zayed	186	24	18	119	13	10,085
Khalifa	1,047	107	99	496	75	52,524
Musaffah	316	53	30	278	26	17,669
Total _ OGV	1,549	185	147	893	114	80,278
HARBOUR VESSELS (HV)						
Zayed	46	4	30	24	7	4,163
Khalifa	55	3	39	31	4	5,406
Total _ HV	101	7	69	55	11	9,569
TOTAL SHIPPING	1,650	192	216	948	125	89,847

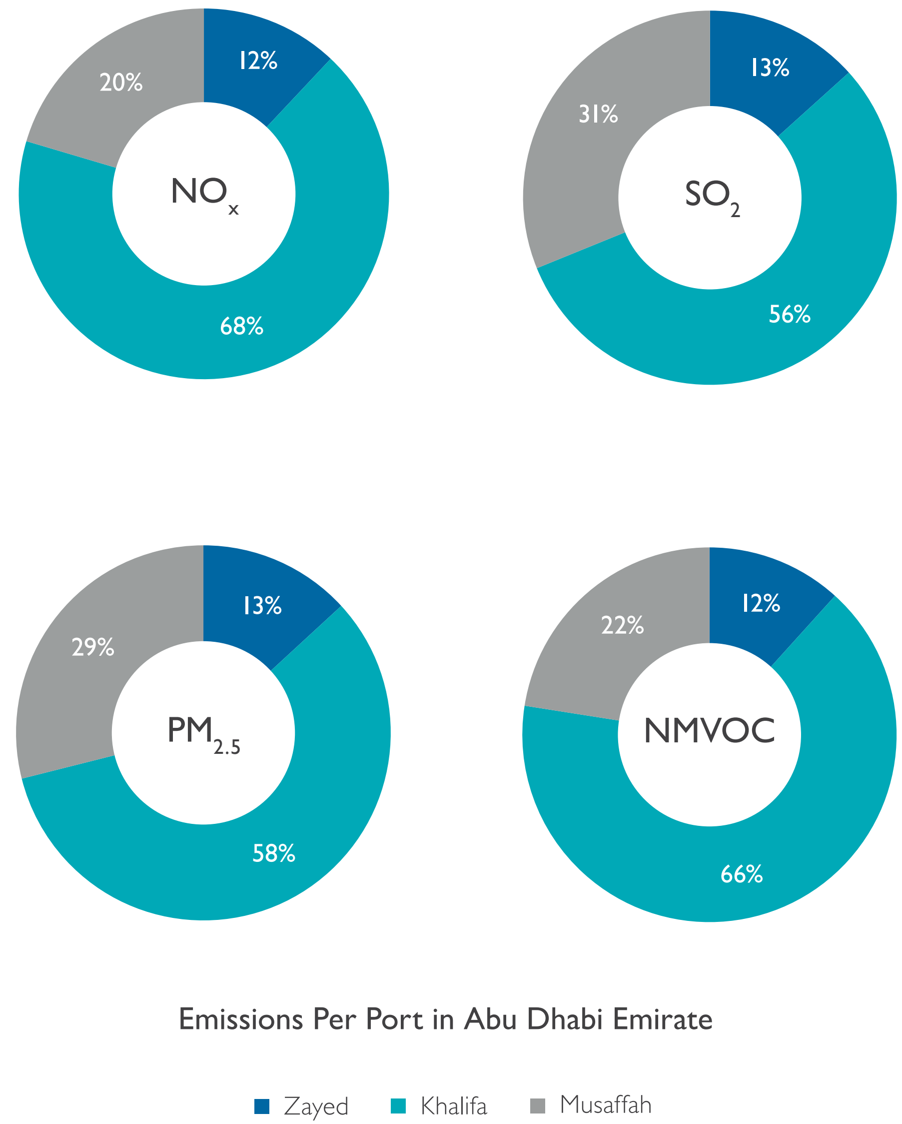


Figure 32: NO_X, SO_2, $PM_{2.5}$ and NMVOC emissions from ocean going vessels in Abu Dhabi Ports in 2015.

Emissions from OGV are estimated based on the vessels operational mode as those occur while arriving and departing from the port area, while manoeuvring and at berth. Figure 19 shows NO_x emissions per operational mode, showing that emissions occurring at berth are the highest, followed by emissions during cruising and manoeuvring. This result is very relevant for urban air quality, as emissions at berth occur closer to populated areas than those during cruising, and they may contribute to high pollution levels there (López-Aparicio et al., 2017). However, it is also important to take into account that only emissions occurring within the port water limits are considered and therefore the time cruising is short compared with the time at berth.

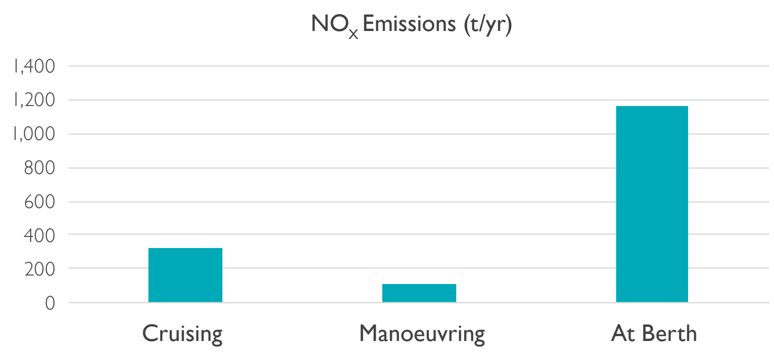
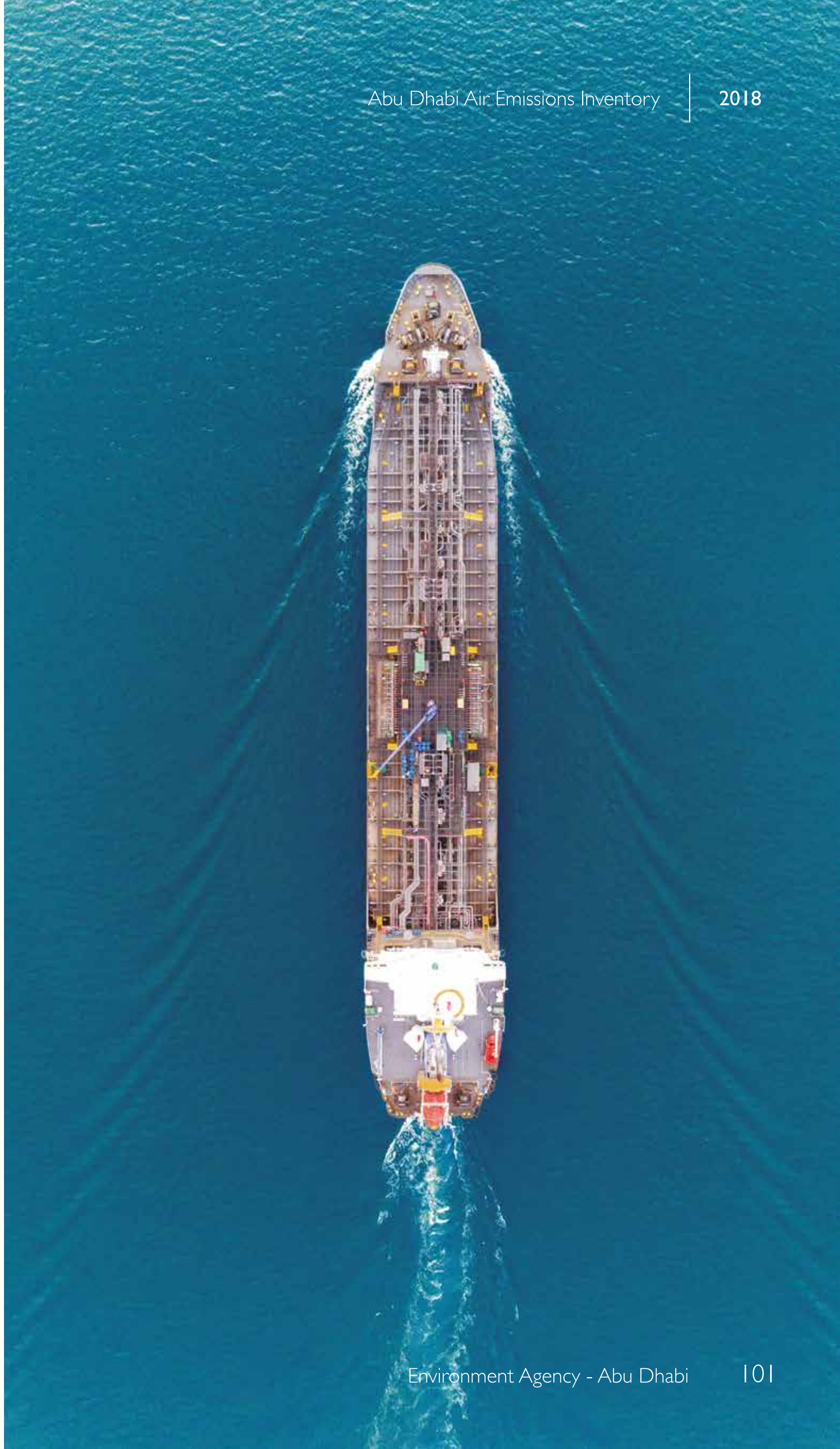


Figure 33: NO_x shipping emissions from Abu Dhabi Ports distributed in the three operational modes.



Aviation Sector

8 Aviation Sector

Emissions from airports are subject to increasing interest in recent years due to the rapid growth of air transportation and the coming expansions to meet capacity needs. In addition, the available scientific literature indicates that emissions for airport activities can affect air quality in urban areas located in the proximity to airports. Therefore it was decided to estimate the emissions of NO_x, CO, NMVOC and PM_{10} from activities in Abu Dhabi Emirate airports as one of the priority sectors. This study focusses on Abu Dhabi International Airport and Al Ain International Airport, both located at relative close distance to urban areas (Figure 34). Abu Dhabi International Airport is one of the fastest growing airport hubs in the world, currently serving over 96 destinations in 56 countries. Al Ain International Airport is Abu Dhabi's second airport, and it is set to gain global recognition as a centre of excellence for technology and innovation through its collaboration with Mubadala Aerospace.

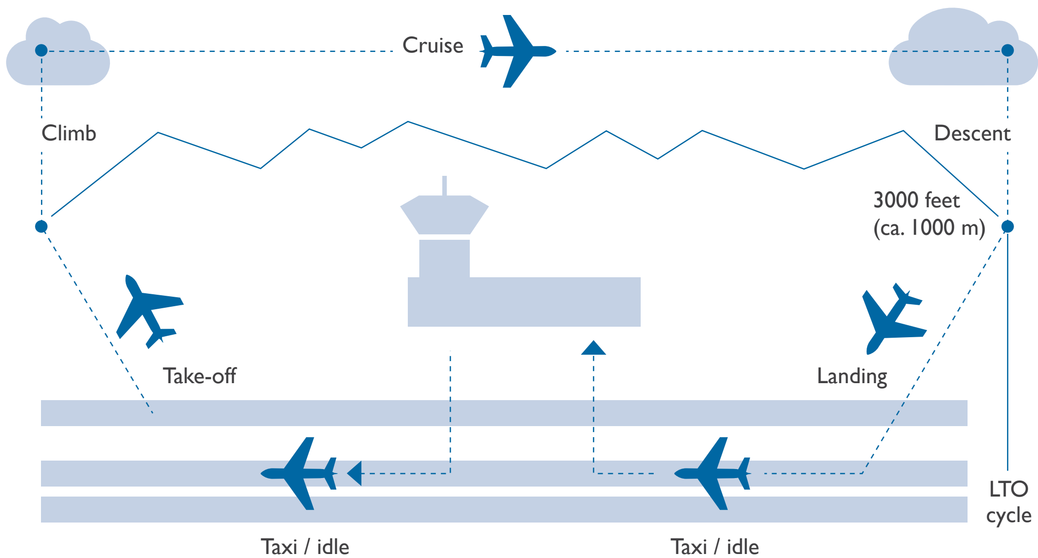


Figure 35: Illustration of landing and take-off cycles (LTO cycles; EMEP/EEA, 2016).

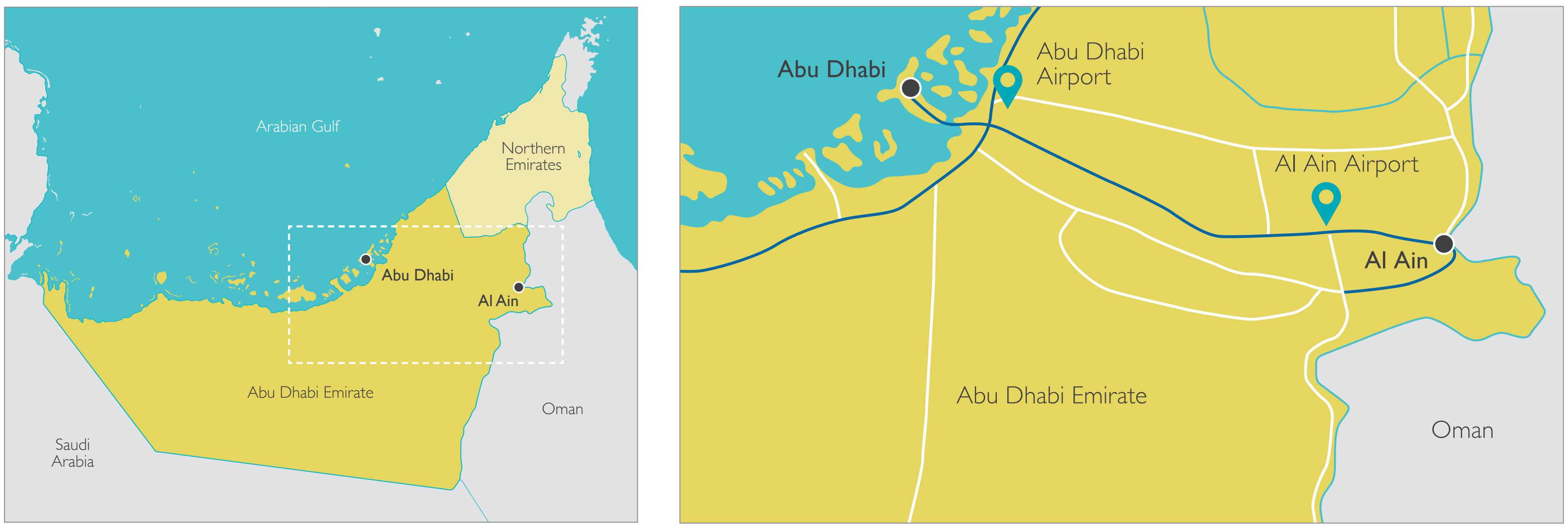


Figure 34: Location of Abu Dhabi International Airport and Al Ain International Airport).

8.1 Method to Estimate Aviation Emissions

The method employed to estimate emissions from aviation in the Abu Dhabi Emirate is recommended in the Airport Air Quality Manual developed by the International Civil Aviation Organization (ICAO, 2011) and in the European guideline for the development of emission inventories (EMEP/EEA, 2016). Emissions of criteria pollutants considered in the inventory are those occurring during landing and take-off cycles (LTO; Figure 21), which consists of four phases of aircraft operations; approaching, taxiing, taking-off and climbing, all occurring above ground level and below 3,000 ft. (915 m).

Due to the lack of specific information about aircraft activity, such as aircraft type, registration number, or airline operator, emissions are based on the number of movements. Aircraft movement makes reference to any aircraft taking-off or landing at an airport. Therefore, the total number of movements can be assumed to be twice the number of LTO cycles.

Emissions (E) for each pollutant i are calculated following a Tier 1 approach based on the product of the number of LTO cycles (#LTO) and a default emission factor (kg/LTO):

$$E_{i,LTO} = \#LTO \times EF_{i,LTO} \quad \text{Equation 10}$$

Emission estimates are based on the monthly number of movement in 2015 at Abu Dhabi International Airport and Al Ain International Airport reported in the Abu Dhabi Statistical Year Book (SCAD, 2016; Figure 22). The data for Abu Dhabi International Airport also includes the Al Bateen Executive Airport data (SCAD, 2016). It is assumed that all the reported movements refer to international flights. Regarding the emission factors, the default emission factors for each pollutant defined in the EMEP/EEA (2016) guideline for a Tier 1 approach have been used. The emission factors are shown in Table 41, and they are considered representative of an average fleet and it is expected that they provide information on the amount of pollutant discharge per LTO-cycle.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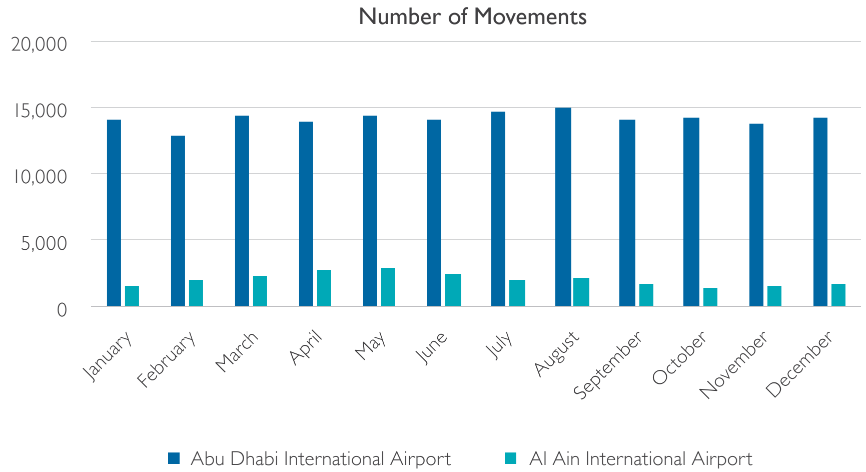


Figure 36: Number of movements in 2015 in Abu Dhabi International Airport and Al Ain International Airport.

Table 42: Emissions factors (kg/LTO) used for estimating emissions for the international aviation.

NO_X	$PM_{2.5}$	CO	SO_2	NMVOC	CO_2
26.0	0.15	6.1	1.6	0.2	5,094

8.2 **Emissions from Aviation Sector**

Emissions from aviation are shown in Table 43. In addition, the contribution from each airport to the total emissions from aviation is shown in Figure 23, using NO_X as an example along with the emissions per month in 2015. Emissions from Abu Dhabi International Airport are much higher than those from Al Ain International Airport, as emissions are directly correlated with the number of flight movements, and the latter airport has less activity. It is noteworthy to highlight that the lowest number of monthly movement in 2015 and therefore the lowest emissions occur in February followed by November, although the activity does not show significant differences between the months (Figure 22 and Figure 23).

Table 43: Emissions of criteria pollutants (t/yr) and CO_2 from aviation in LTO cycles at the international airports in Abu Dhabi Emirate for the year 2015.

	Emissions from aviation (for international LTO; 2015)					
	NO_X (t/yr)	PM (t/yr)	CO (t/yr)	SO_2 (t/yr)	NMVOC (t/yr)	CO_2 (t/yr)
Abu Dhabi Int. Airport	2,210	13	518	136	17	433
Al Ain Int. Airport	320	2	75	20	2	63
TOTAL	2,529	15	593	156	19	496

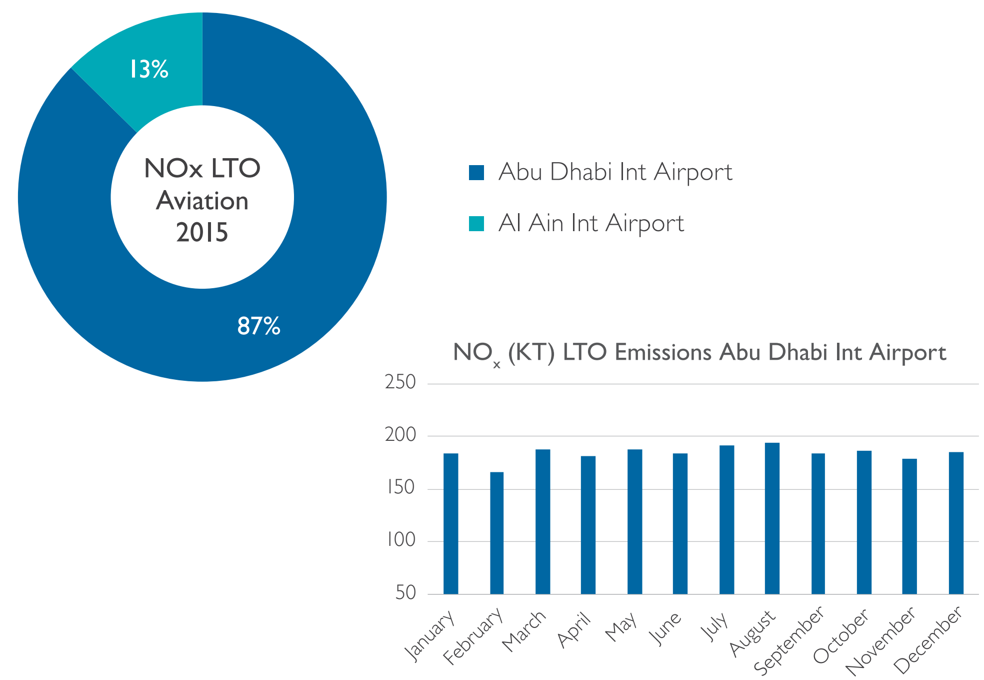


Figure 37: Contribution to NO_X emissions from aviation (LTO cycles) from Abu Dhabi and Al Ain International airports (left) and NO_X LTO emissions distributed per month in the year 2015.

Agriculture Sector

9 Agriculture Sector

Crop production and agricultural soil are sources of PM and NMVOC emissions. This sector is not a big contributor to emissions and the share to total emissions in Abu Dhabi may be negligible. However, it is important to include it in order to have a comprehensive emission inventory and characterisation of emitters. NMVOC emissions are biogenic, and derive from vegetation such as trees, and crop production and agricultural soil. PM emissions in this sector result from agricultural processes, such as soil cultivation and harvesting. Crop production and agricultural soil are important sources of ammonia (NH_3), and are particularly associated with the use of mineral Nitrogen fertilisers, livestock manure, organic waste applications and crop processes. However, NH_3 is not a criteria pollutant and therefore is not included in this emission inventory. This compound can be considered in further work or updates of the emission inventory.

9.1 Method to Estimate Agriculture Emissions

Emissions are estimated following a Tier 1 approach (Equation 11) as this sector is not one of the key sectors when addressing the pollutants of interest. This approach and the use of a default emission factor add certain uncertainties. The EEA/EMEP guideline (2016) and other sources evaluated (Shrestha et al., 2013) do not include specific NMVOC emission factors for fruit trees or vegetable crops. Therefore emissions of pollutant i (kg/yr) are estimated based on the product of areas covered by crop (AR_{area}; ha) and default emission factors (EF_i; kg.ha–1.yr–1) following Equation 11.

$$E_i = AR_{area} \times EF_i \quad \text{Equation 11}$$

Table 44 and Table 45 show the activity data and emission factors used to estimate emissions fromagriculture.

Table 44: Agriculture area distributed by type and region (Source; SCAD 2016). Units: donums.

	Abu Dhabi	Al Ain	Al Dhafra
Fruits Trees	23,175	145,779	103,368
Field Crops	3,540	38,270	6,367
Vegetable Crops	3,496	6,429	3,872
Current fallow	32,094	179,706	69,500

Table 45: Emission factors used for estimating emissions from agriculture (EEA/EMEP, 2016).

	PM10 (g/ha)	PM2.5 (g/ha)	NMVOC (g/ha)
Emission Factors	1.56	0.06	0.86

9.2 Emissions from Agriculture Sector

Table 46 and Figure 24 show emissions from agriculture in Abu Dhabi, Al Ain and Al Dhafra, distributed between fruit trees, field crops, vegetable crops and fallow. Total emissions from agriculture are relatively low, with total PM10, PM2.5 and NMVOC emissions around 96, 4 and 53 t/yr, respectively, in Abu Dhabi Emirate. The magnitude of the emissions is directly related to the area covered by agricultural soil, as the default emission factors are considered representative of all agricultural soil (Table 45). Al Ain, the region with largest agricultural activity, is the biggest contributor to agricultural emissions (60 %) followed by Al Dhafra (30 %) and Abu Dhabi (10 %; Figure 24). Most of the agricultural areas are covered by fruit trees and fallow.

Table 46: Emissions (t/yr for PM10, PM2.5 and NMVOC) from agriculture in Abu Dhabi Emirate in 2015 and distributed among the regions. Veg. Crops refers to vegetable crops, and C. Fallow refers to current fallow.

	Emissions from aviation (for international LTO; 2015)								
	Abu Dhabi	Al Ain	Al Dhafra	Abu Dhabi	Al Ain	Al Dhafra	Abu Dhabi	Al Ain	Al Dhafra
Fruit Trees	3.62	22.74	16.13	0.14	0.87	0.62	1.99	12.54	8.89
Field Crops	0.55	5.97	0.99	0.02	0.23	0.04	0.30	3.29	0.55
Veg. Crops	0.55	1.00	0.60	0.02	0.04	0.02	0.30	0.55	0.33
C. Fallow	5.01	28.03	10.84	0.19	1.08	0.42	2.76	15.45	5.98
TOTAL	9.72	57.75	28.56	0.37	2.22	1.10	5.36	31.84	15.75

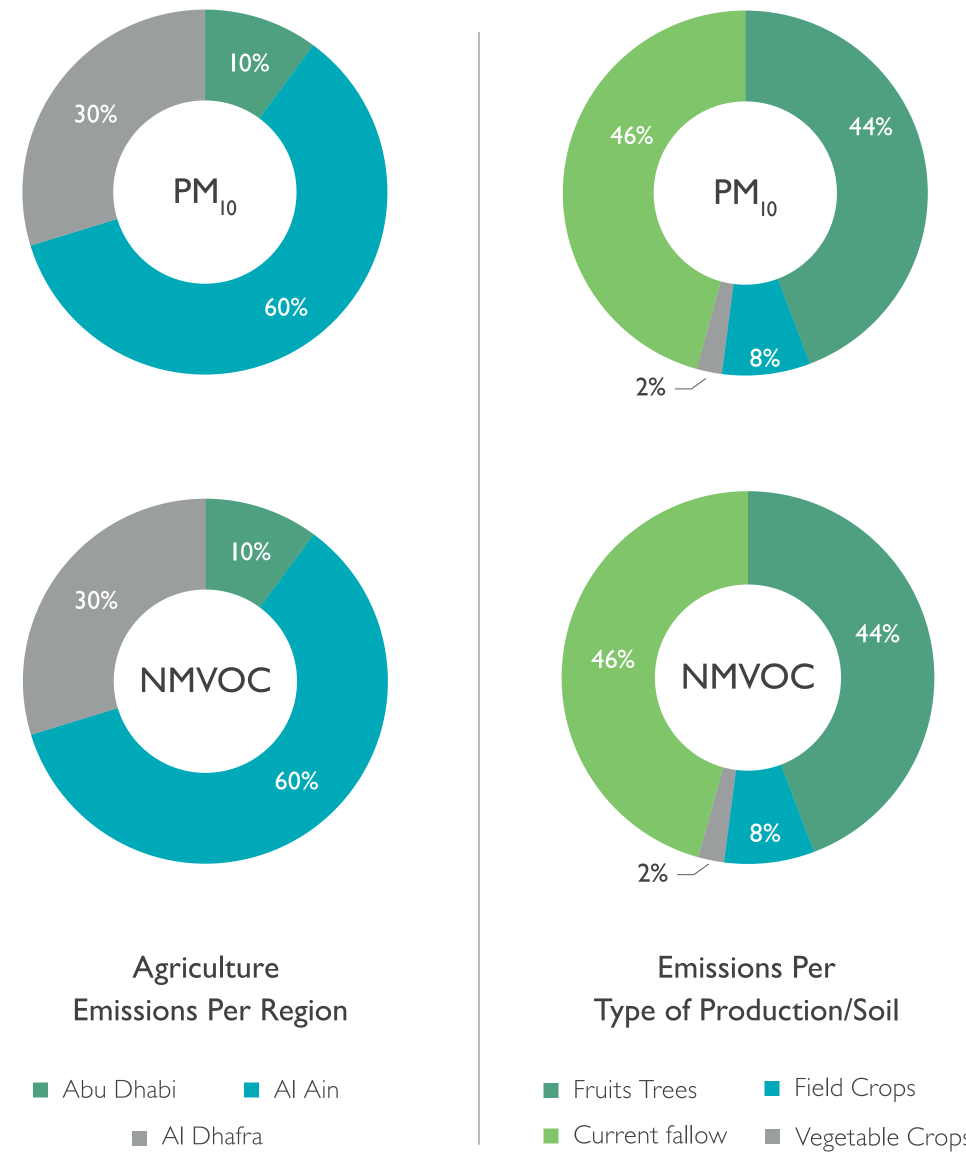
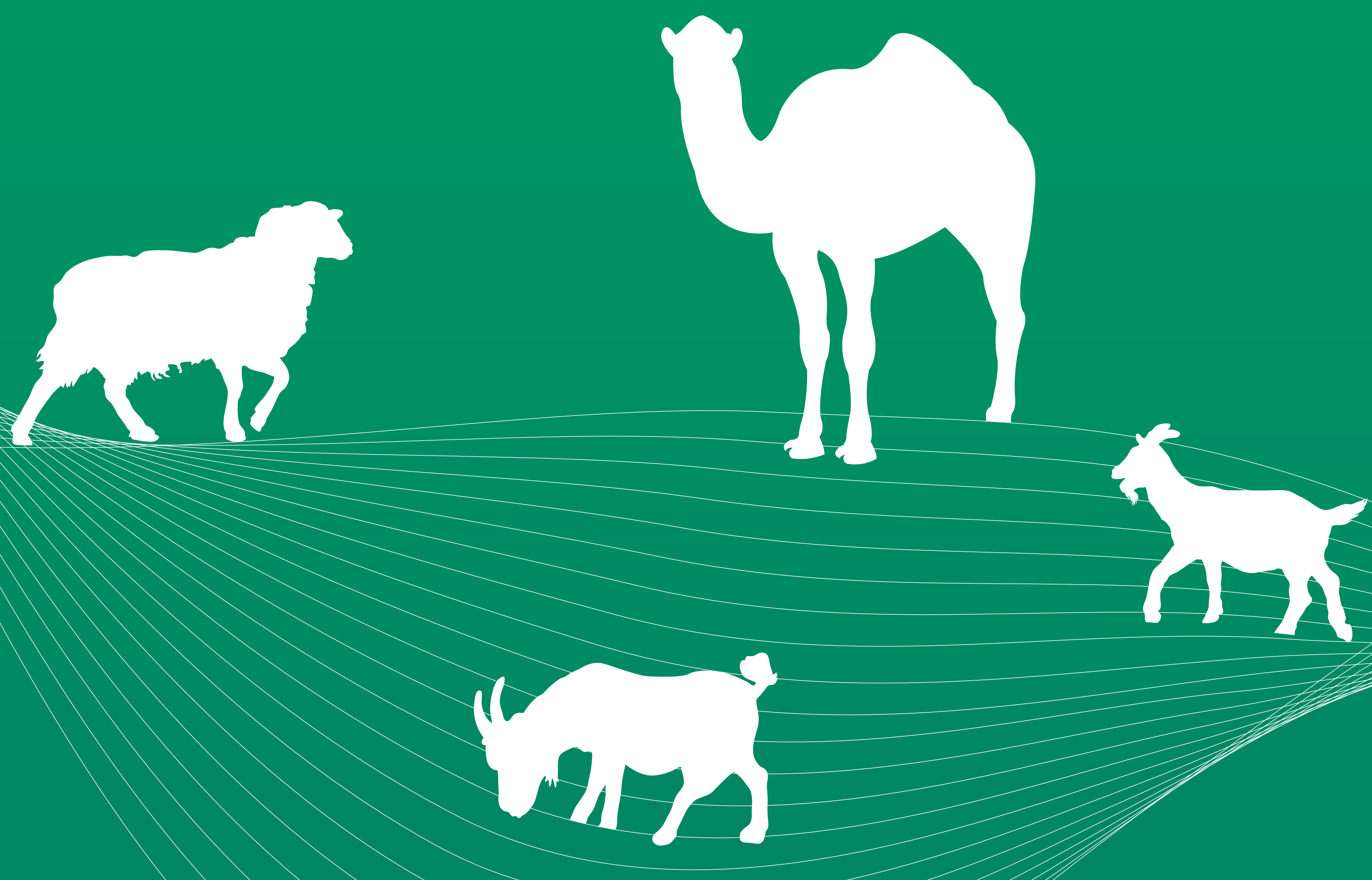


Figure 38: Distribution of PM10 and NMVOC emissions in Abu Dhabi Emirate among the regions (left) and the type of production / soil (right) for the year 2015.



Livestock Sector

10 Livestock Sector

Emissions from livestock are those associated with the excreta of agricultural livestock and with manure management. These emissions are especially relevant for NH_3, NO and NMVOC. In our study we consider NMVOC and in addition PM_{10} and $PM_{2.5}$. Based on the data availability, and following the decision tree in EEA/EMEP (2016), a Tier 1 is selected to estimate emissions.

10.1 Method to Estimate Livestock Emissions

Emissions of pollutant i are calculated based on the number of animals of a particular category j and the EF for the specific animal category (kg/AAP; Equation 12). The number of animals in each category in 2015 was obtained from the Statistical Yearbook of Abu Dhabi (SCAD, 2016), where the livestock is distributed as number of sheep and goats (combined), cattle and camels in the Emirate (Table 47). In addition, information about number of chickens, including broilers, egg-laying hens and hens was obtained directly from SCAD at the Emirate level (Table 48). In the case of broilers, we used the total capacity of farms in the Emirate to account for the lifetime of broilers, and therefore the difference between the broilers produced and the existing annual livestock.

Emission factors used in our study are shown in Table 48. Emission factors for PM from camels are not available and in this case, we used emission factors defined for horses since both animals have similar manure characteristics.

$$E_i = AAP_j \times EF_{i,j} \quad \textit{Equation 12}$$

Table 47: Number of animals per category (2015; Source SCAD, 2016).

	Livestock	Number of animals
Abu Dhabi	Sheep and goats	617,886
Abu Dhabi	Cattle	6,677
Abu Dhabi	Camels	74,371
Al Ain	Sheep and goats	1,970,057
Al Ain	Cattle	42,918
Al Ain	Camels	209,323
Al Dhafra	Sheep and goats	496,534
Al Dhafra	Cattle	1,602
Al Dhafra	Camels	100,193
Abu Dhabi Emirate	Broilers	2,551,500
Abu Dhabi Emirate	Egg-laying hens	2,109,360
Abu Dhabi Emirate	Hens	173,900

Table 48: Emissions factors (kg/AAP) for PM_{10}, $PM_{2.5}$ and NMVOC from livestock (EEA/EMEP, 2016). *NMVOC Emission factor is an average of the EF for sheep and goats.

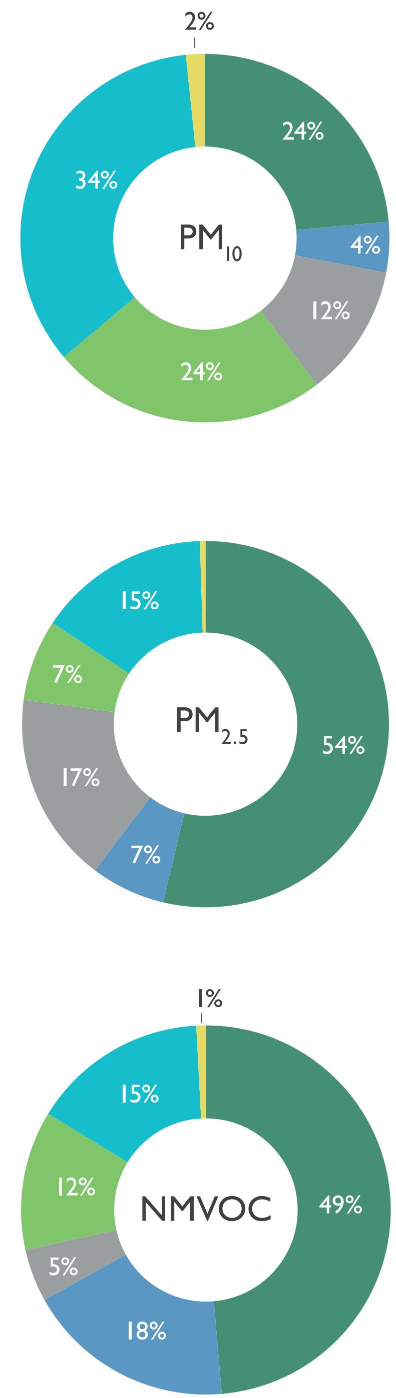
	EF_{PM10}	$EF_{PM2.5}$	EF_{NMVOC}
Sheep and goats	0.0556	0.0556	0.355*
Cattle	0.63	0.41	8.05
Camels	0.22	0.14	0.27
Broilers	0.069	0.009	0.108
Egg-laying hens	0.119	0.023	0.165
Hens	0.069	0.009	0.108

10.2 Emissions from Livestock Sector

Table 49 and Figure 25 show emissions of PM_{10}, $PM_{2.5}$ and NMVOC in Abu Dhabi Emirate in 2015 distributed among the animal category, and among regions in the case of sheep and goats, camels and cattle. Total emissions of PM_{10}, $PM_{2.5}$ and NMVOC from livestock in Abu Dhabi Emirate were approximately 727,319 and 2,255 tonnes, respectively. Al Ain seems to be the region contributing the most to emissions from livestock, followed by Abu Dhabi and Al Dhafra, although regional distribution of poultry is not available. Sheep and goats are the largest contributor to emissions (Figure 25) of PM_{10}, $PM_{2.5}$ and NMVOC due to the high number of animals in this category, followed by egg-laying hens.

Table 49: Emissions (t/yr) of PM_{10}, $PM_{2.5}$ and NMVOC from livestock for the year 2015.
*Represents emissions in the entire Emirate.

	PM_{10} (t/yr)			$PM_{2.5}$ (t/yr)			NMVOC (t/yr)		
	Abu Dhabi	Al Ain	Al Dhafra	Abu Dhabi	Al Ain	Al Dhafra	Abu Dhabi	Al Ain	Al Dhafra
Sheep / goats	34	110	28	34	110	28	220	700	177
Cattle	4	27	1	3	18	1	54	345	13
Camels	16	46	22	10	29	14	20	57	27
Broilers	176*			23*			276*		
Egg-laying hens	251*			49*			348*		
Hens	12*			2*			19*		
TOTAL	727*			319*			2,255*		



Emissions Per Type of Livestock in Abu Dhabi Emirate

- Sheep / Goats
- Cattle
- Camels
- Broilers
- Egg-laying Hens
- Hens

Figure 39: Emission distribution from livestock in Abu Dhabi Emirate among the type of livestock, for the year 2015.

11 Fugitive Emissions at Service Stations

Fugitive emissions refer to non-combustion emissions that occur as an escape or release of volatile components of fuels. Most of the fugitive emissions occur from refining, transport and distribution of oil products, with the most relevant component being NMVOC. This sub-sector refers to the fugitive emissions in service stations and includes filling and withdrawal of the petrol tanks at the station and emissions while refuelling petrol cars. Evaporative emissions from diesel vehicles are considered to be negligible due to the presence of heavier hydrocarbons and the relatively low vapour pressure of diesel fuel.

During the writing of this report, detailed information about the amount of petrol consumed or sold at service stations was not available. The approach selected is based on Shrestha et al. (2013), who establish that evaporative emissions at the service stations can be calculated based on the petrol consumed or sold. The input data considered in our study is shown in Table 50, representing the amount of fuel consumed in 2014 in the transport sector. The data is distributed according to land transport and transport via pipelines, water transport, air transport, warehousing and support activities for transportation, and postal and courier activities categories. The petrol consumption was selected in those economic activities that are relevant (i.e. land transport and transport via pipelines, and postal and courier activities). The fuel consumption represents the year 2014; thus the values are recalculated to represent 2015 based on the total petrol consumption for transportation in 2015 (23,413,135 GJ; SCAD, 2016) and assuming that the share of the different economic activities is kept constant. Around 3,321,871 GJ (approx. 66,973 t) of petrol is estimated to be used for land transportation in Abu Dhabi Emirate in 2015. Considering an EF_{NMVOC} of 2,880 (kg/kt petrol consumed/sold; Shrestha et al., 2013), the fugitive emissions of NMVOC from distribution at service stations was estimated to be approximately 192.88 t.

Table 50: Fuel consumption in the transport sector in 2014 (Source SCAD) and 2015 (Estimated).

	2014	2015
Economic Activity	Petrol (GJ)	Petrol (GJ)
Land transport and transport via pipelines	3,290,664	3,287,949
Water transport	38,338	38,306
Air transport	19,917,162	19,900,730
Warehousing and support activities for transportation	152,354	152,228
Postal and courier activities	33,950	33,922
TOTAL	23,432,468	23,413,135

12 Recommendations

The emission inventory presented in this report constitutes a significant step forward towards a comprehensive overview of the anthropogenic emissions occurring in Abu Dhabi Emirate. Since emission inventories are built over time through a process of continuous updating of both input data and methodological approaches to estimate emissions, the present inventory also provides valuable experiences to include in the future inventorying.

John and Daham (2009) developed a preliminary emission inventory for Abu Dhabi Emirate for the year 2009. The emission inventory presented in this report represents an update for the year 2015 with a reduction of previously identified uncertainties, as well as achieving a higher degree of completeness. The most significant improvements concern the emissions from road transport, as the current version is a bottom-up emission estimate for the entire Emirate and not only for the cities of Abu Dhabi and Al Ain. For future updates of the emission inventory, it is recommendable to include CO_2 as an additional compound in the inventory. Another significant improvement regarding the emission inventory from 2009 is that in the current version includes sectors, which were previously lacking, such as aviation, shipping, agriculture, livestock and fugitive emissions from service stations.

The evaluation of both emission inventories and the process followed to fulfil the update indicates that emission inventories of criteria pollutants for Abu Dhabi Emirate should be updated every 2 or 3 years. In a future update, it is recommended to perform an evaluation and prioritization of sectors/subsectors for which the method needs to be updated (e.g., selected emission factors), target the identified gaps, and design an effective data collection process based on the lessons learned during the work carried out in this project. For instance, emissions from the industry sector represent the emissions of only those entities that have reported during our data collection process. In a next reiteration, it is recommendable to carry out an assessment of methods to reduce such gaps. This may include for instance, implementation of best practises for scaling up emissions to represent the entire sector, or top-down approaches based on the statistical information about fuel consumption or production in the industrial sector at the Emirate level. In addition, the use of stack CEM monitoring data from the main industries will increase the quality of the emission data.

Emission factors constitute one of the most important variables in the development of emission inventories, and they very much vary based on local features. Therefore, it is recommendable to assess the feasibility of development of local emission factors, especially in the road transport.

Last recommendation, but the most important, is to continue to work in close collaboration with all the related government and private entities that contributed in the elaboration of the Abu Dhabi Air Emissions Inventory, without whom, it would not have been possible. This collaboration will also help in the continuous improvement of the air quality for the benefit of our natural environment and the inhabitants of Abu Dhabi Emirate.

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Appendix

14 Appendix

14.1 Acronyms and Abbreviations

Abbreviation	Full name
ADAC	Abu Dhabi Airports Company
ADCO	Abu Dhabi Company for Onshore Petroleum Operations Ltd
ADFCA	Abu Dhabi Food Control Authority
ADGAS	Abu Dhabi Gas Liquefaction Company Limited
ADMA-OPCO	Abu Dhabi Marine Operating Company
ADNOC	Abu Dhabi National Oil Company
ADOC	Abu Dhabi Oil Company
ADP	Abu Dhabi Ports Company
ADSSC	Abu Dhabi Sewerage Services Company
ADT	Average Daily Traffic
ADWEA	Abu Dhabi Water and Electricity Authority
ADWEC	Abu Dhabi Water and Electricity Company
AED	United Arab Emirate Dirham
AMPC	Al Mirfa Power Company
AQNCC	Air Quality, Noise and Climate Change Section, EAD
APC	Arabian Power Company
BOROUGE	Abu Dhabi Polymers Company Limited
BTU	British Thermal Unit
CB	Company Buses
CEM	Continuous Emission Measurements
CH_4	Methane
CHP	Combined Heat and Power
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CWM	Centre of Waste Management
DoH	Department of Health
DoT	Department of Transport
DPM	Department of Urban Planning and Municipalities
EAD	Environment Agency - Abu Dhabi
ECPC	Emirates CMS Power Company
EEA	European Environment Agency
EF	Emission Factor
EGA	Emirates Global Aluminium
ELIXER	ADNOC Linde Industrial Gases Company Limited
EMAL	Emirates Aluminium
EMEP	The European Monitoring and Evaluation Programme
ESMA	Emirates Authority for Standardization & Metrology
EWS-WWF	Emirates-Wildlife Society
FERTIL	Ruwais Fertilizer Industries
GASCO	Abu Dhabi Gas Industries Limited
GDP	Gross Domestic Product
Gg	Gigagram
GWh	Gigawatt Hour
GTTPC	Gulf Total Tractebel Power Company
ha	Hectare

HDV	Heavy Duty Vehicle
HV	Harbour Vessels
ICAO	International Civil Aviation Organization
IDB	Industrial Development Bureau
Imp. gal	Imperial Gallon
kWh	Kilowatt Hour
kg	Kilogram
L	Litre
lb	Pound
LGV	Light Goods Vehicle
LPG	Liquefied Petroleum Gases
LTO	Landing and Take-Off Cycles
m^3	Cubic Metre
MBTU	Million British Thermal Units
MOCCAE	Ministry of Climate Change and Environment
MOENR	UAE Ministry of Energy and Industry
MJ	Megajoule
n.a.	Not Applicable
NDC	National Drilling Company
NH_3	Ammonia
NILU	NILU - Norwegian Institute for Air Research
NMVOC	Non-methane Volatile Organic Compounds
NO_X	Nitrogen Oxides
N.R.	Not Reported
O_2	Oxygen
OGV	Oceangoing Vessels
QCC	Abu Dhabi Quality and Conformity Council

PJ	Petajoule
PM	Particulate Matter
RPC	Ruwais Power Company
RSB	Regulation and Supervision Bureau
SAPCO	Shuweihat Asia O & M Company
SB	School Buses
SCAD	Statistics Centre - Abu Dhabi
SCIPCO	Shuweihat CMS International Power Company
SO_2	Sulphur Dioxide
SO_X	Sulphur Oxides
STEAM	Strategic Transportation Evaluation and Assessment Model
t	Metric Tonne
t/yr	Tonne Per Year
TAKREER	Abu Dhabi Oil Refining Company
TAPCO	Taweelah Asia Power Company
TJ	Terajoule
Total ABK	Total Abu Al Bukhoosh
TPM	Total Particulate Matter
U.S. gal	US Gallon
UAE	United Arab Emirates
US EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compounds
ZADCO	Zakum Development Company
ZonesCorp	Higher Corporation for Specialized Economic Zones

Note: **The Abu Dhabi Urban Planning Council (UPC) and the Department of Municipal Affairs have merged to become the Department of Urban Planning and Municipalities (DPM).**

n.a (not applicable) and N.R. (not reported) are terms used to indicate when information in a certain table cell is not provided, either because it does not apply to a particular case in question or because the answer is not available.

14.2 Conversion Factors

Convert from	Convert to	Multiply by
1 L	m^3	1
1 U.S. gal	L	3.78541
1 L crude oil (35.6 API) (60F, density = 825 kg/m^3)	t crude oil (35.6 API) (60F, density = 825 kg/m3)	0.000847
1 L diesel (60F, density = 885 kg/m^3)	t diesel (60F, density = 885 kg/m^3)	0.00089
1 L gas oil (60F, density = 890.13 kg/m^3)	t gas oil (60F, density = 890.13 kg/m^3)	0.00089
1 L petrol (60 F, density = 737 kg/m3)	t petrol (60 F, density = 737 kg/m^3)	0.00074
1 L LPG	t LPG	0.0006
1 Gg crude oil	TJ crude oil (net calorific value)	42.3
1 Gg diesel and gas oil	TJ diesel and gas oil (net calorific value)	43
1 Gg petrol	TJ petrol (net calorific value)	44.3
1 Gg LPG	TJ LPG (net calorific value)	47.3
1 Gg natural gas	TJ natural gas (net calorific value)	48
1 m^3 of natural gas	MJ of natural gas	38.1396
1 GJ	MJ	1,000
1 TJ	GJ	1,000
1 PJ	TJ	1,000
1 Gg	t	1,000
1 Gg	kg	1.00E+06
1 MBTU	GJ	1.06
1 lb	t	0.00045
1 Imp. gal	L	4.54609
1 donum	m_2	1,000
1 ha	m_2	10,000

Note: The units are denoted as the following:

L (litre), m^2 (square metre), m^3 (cubic metre), kg (kilogram, 10^3 g), t (metric tonne, 10^6 g), Gg (gigagram, 10^9 g), BTU (British thermal unit), MBTU (million British thermal unit, 10^6 BTU), U.S. gal. (U.S. gallon), Imp. gal. (imperial gallon), J (joule), MJ (megajoule, 10^6 J), GJ (gigajoule, 10^9 J), TJ (terajoule (TJ) (10^{12} J), PJ (petajoule, 10^{15} J), lb (pound, 453.592 g), ha (hectare).

14.3 List of Tables

14.4 List of Figures

Tel. 02 6934444
customerhappiness@ead.ae
www.ead.ae