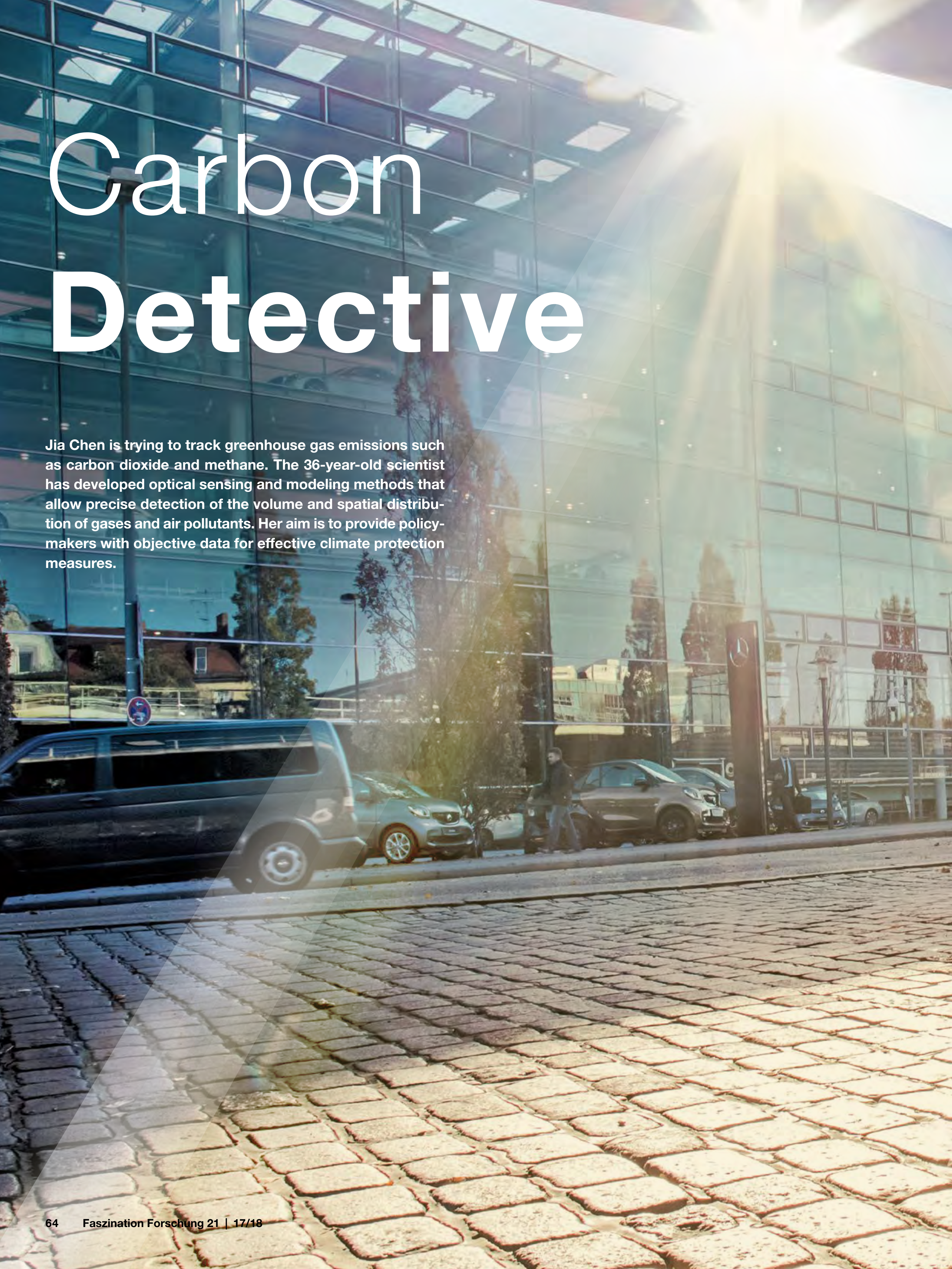


Carbon **Detective**

Jia Chen is trying to track greenhouse gas emissions such as carbon dioxide and methane. The 36-year-old scientist has developed optical sensing and modeling methods that allow precise detection of the volume and spatial distribution of gases and air pollutants. Her aim is to provide policymakers with objective data for effective climate protection measures.

Environmental Sensing and Modeling
www.esm.ei.tum.de

Picture credit: ediundsepp/TUM

Karsten Werth

Treibhausgasen auf der Spur

Der Klimaschutz ist eine der großen Herausforderungen für die Menschheit im 21. Jahrhundert. Prof. Jia Chen hat eine Messmethode entwickelt, um mit wenigen kompakten Sensoren die Treibhausgasemissionen einer Stadt zu erfassen. Ihr Ziel ist es, die Menge und Verteilung von klimaschädlichen Gasen wie Kohlendioxid, Methan und Kohlenmonoxid in der Luft exakt zu messen. „Um die Wirksamkeit von Klimaschutzmaßnahmen einzuschätzen, sind objektive Messungen notwendig. Berechnungen und Schätzungen mit vielen Unbekannten reichen nicht aus", sagt die Professorin für Umweltsensorik und Modellierung an der TUM.

Chen's Messmethode basiert auf Infrarotspektrometern, die sich nach der Sonne ausrichten. Weil jedes Gasmolekül einen ganz bestimmten Teil des Lichtspektrums absorbiert, lässt es sich anhand seines „spektralen Fingerabdrucks" eindeutig identifizieren. Da die Sonne als Lichtquelle genutzt wird, kann eine ganze Luftsäule erfasst werden. Vermessen werden solche atmosphärischen Säulen außerhalb und – in Windrichtung – innerhalb einer Stadt. Die Unterschiede zwischen den Messungen zeigen dann, wie viele Emissionen in der Stadt generiert werden. In Verbindung mit Winddaten lässt sich mit dieser sogenannten Differenzialsäulenmessung genau berechnen, wie sich die Treibhausgase räumlich verteilen. Im nächsten Schritt will die 36-jährige Ingenieurin auch die Erfassung von Stickoxiden in das Messkonzept integrieren.

Ein Netzwerk von automatisierten, kompakten Sensorsystemen soll als Pilotprojekt in München aufzeigen, wo Emissionen entstehen, wohin sie sich bewegen und welche Auswirkung ihre Verteilung auf die Luftqualität hat. „Die Stadt München könnte eine Vorreiterrolle einnehmen, wenn es darum geht, die Wirksamkeit von Klimaschutzmaßnahmen objektiv zu überprüfen", sagt Chen. □

When she steps out onto the roof terrace, Jia Chen is greeted by an impressive panoramic view of downtown Munich. Up here, however, the Professor of Environmental Sensing and Modeling is concerned less with the sightseeing highlights of the Bavarian capital and more with the equally prominent chimneys that tower over the city's heat and power plants. They may be among the cleanest of their kind, but – besides traffic – the municipal power and heating facilities are some of the city's biggest carbon dioxide emitters. The measurement instruments set up on the roof of TUM's Department of Electrical and Computer Engineering are intended to provide an accurate picture of urban air pollutants and their origins.

Conventional measurements fall short

"If you just take measurements at a single point, for instance on a power plant chimney, the results are not particularly meaningful because the pollutants spread out from there in a gas cloud," describes Chen, indicating plumes of exhaust gas in the sky. "You don't know in what direction the gases are moving and what effect their distribution will have on air quality." And horizontal dispersion of pollutants by the wind is not the only factor, she emphasizes. Measurements should also include vertical dynamics in the atmosphere: Depending on ground temperature, gases dissipate upwards at different speeds, mixing with the air. However, surface and point sensors are not able to measure this.

Bigger picture with new method

Chen specializes in optical gas sensors and their application in environmental monitoring. Together with Professor Steven C. Wofsy from Harvard University in Cambridge (USA), Jia Chen has developed a new method of quantifying the pollution emitted within a city using a few compact sensor systems. These are based on infrared spectrometers which track the sun. Since each gas molecule absorbs the light spectrum at a specific wavelength, it can be uniquely identified using its "spectral fingerprint". Carbon dioxide (CO_2), for instance, absorbs sunlight at wavelengths between 1565 and 1620 nanometers (nm) – methane, by contrast, at wavelengths between 1627 and 1696 nm. Since the sun is used as the light source, an entire column of air can be recorded in this way. These atmospheric columns are measured both outside (upwind) and inside (downwind) the city. The differences between the measurements reveal the level of emissions generated within the city. In conjunction with wind data, these differential column measurements enable precise calculation of greenhouse gas emissions. Thanks to their high sensitivity, the sensors work even on days with partial cloud cover. However, they are not suitable for use at night or in rainy weather. ▷

Graphics: ediundsepp, Source: Jia Chen

Tracking greenhouse gas emissions: An optical sensor measures the number of different gas molecules in the column of air downwind of an emissions source, in other words after the air column traveling through the emissions source or the city. A second sensor measures the gas in the air upwind. Based on the difference between the two air columns, Jia Chen then calculates how much carbon dioxide and methane was emitted and where, using atmospheric transport models. In the next step, this method will be applied to other air pollutants like nitrogen oxides. The method has been validated in measurement campaigns (Chen et al., 2016).

On the roof of TUM's Department of Electrical and Computer Engineering, Jia Chen and her team operate the only sensor system permanently installed in Munich that measures greenhouse gases such as carbon dioxide and methane. The sensor system is equipped with a FTIR spectrometer and a patent-pending automated weather-resistant housing (Heinle and Chen, 2017). Its cover follows the movement of the sun and automatically closes if it rains, in order to protect the optical and electronic components. The gas fired district heating plant Theresienstrasse operated by Munich City Utilities (SWM) is visible in the background (right).

"Objective measurements are the only way to answer questions about the effectiveness of climate protection activities"

Jia Chen

Helping to inform political decision-making

The advances in environmental sensing could help to reduce greenhouse gas emissions and thus slow global warming. Efficient, long-term monitoring of urban air quality also makes it easier to determine the success of climate and environmental protection measures. Chen and her team have been gathering data since 2015 using her sensor system. She clarifies: "It is important to review objectives and action plans on a regular basis and adjust them as necessary – which is where we can support policymakers."

Another of Chen's research interests lies in investigating technologies considered to be eco-friendly, such as the passive house concept, geothermal energy and e-mobility. Do all of these really lead to reduced emissions? "Answering this question calls for objective measurements. Calculations or estimates with unknown variables are not good enough," declares Chen.

How much methane is escaping?

Even today, not much is known about actual levels of greenhouse gas pollution in city air, for instance. Chen explains that natural gas escapes from weak points in pipelines and storage facilities. In Boston (USA), her colleagues took measurements that show that leaky gas pipes are allowing around three per-

Side-by-side measurements: Jia Chen and her colleagues calibrate their sensors before a six-week series of carbon dioxide, methane, carbon monoxide and nitrogen oxide measurements in Munich in autumn 2017. The results will contribute to a larger international study. Left to right: Ralph Kleinschek (German Aerospace Center – DLR), Florian Dietrich, Jia Chen, Michael Wedrat (TUM).

cent of methane – the primary component of natural gas – to escape. "Natural gas is considered a greener fuel than coal because it generates less carbon dioxide when combusted. But what about the methane that seeps into the atmosphere before combustion? Methane has a much stronger greenhouse effect than CO_2. So we need to keep an eye on that," points out Chen.

Munich as proof of concept

The measurement station developed and operated by Chen's team is the only one permanently installed in Munich that measures greenhouse gases such as CO_2 and methane. The city's CO_2 emissions are calculated according to a "bottom-up" approach – that is, upscaling individual emitters such as factories, power plants and vehicles with economic data or spatial proxies. However, this approach includes considerable uncertainties because many parameters are unknown. For example, combustion efficiencies cannot be clearly established. In addition, emitters that are unaccounted for, such as pipeline leaks, will not be included.

Chen's goal is to determine the emissions by combining the concentration measurements taken by six automated stations with atmospheric transport modeling. To achieve this, she is liaising with city authorities and the municipal utilities provider Stadtwerke München. The planned monitoring network would reveal how much greenhouse gas and air pollutants are being emitted – and exactly where. As a next step, she is looking to integrate nitrogen oxide detection into the measuring system. "Objective measurements are the only way to answer questions about the effectiveness of climate protection activities," asserts Chen. "So the city of Munich could play a pioneering role in the objective review of measures designed to protect the climate."

Chen's team uses sensors to help identify emissions sources and sinks. "If we know how many molecules of a particular gas are present in the atmosphere and how they are transported, we can work backwards to see where they come from – for instance a landfill site, natural gas storage unit or agricultural holding. We can also see how effectively forests and parks are absorbing carbon," says Chen.

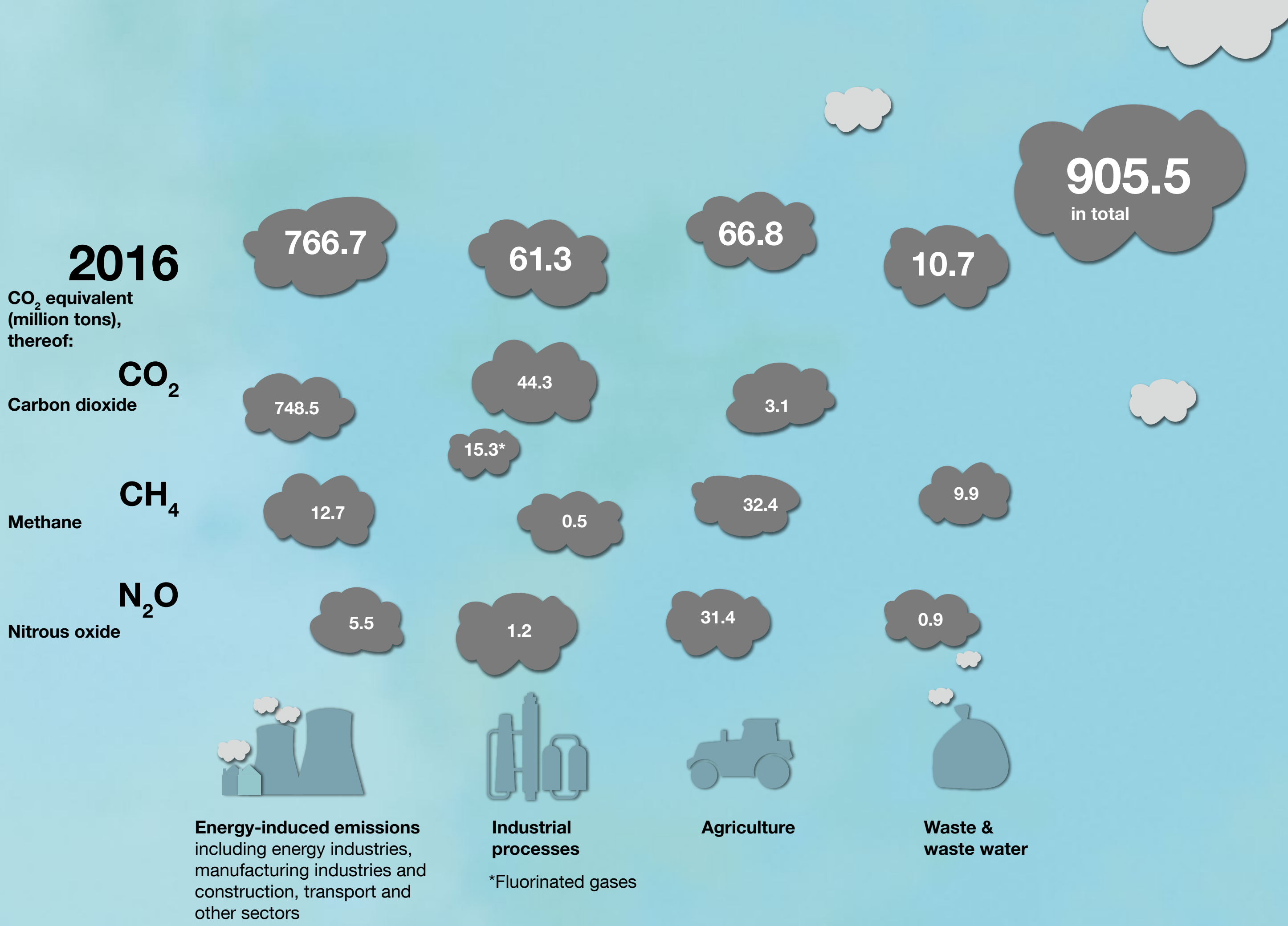
Getting started

A six-week series of measurements in autumn 2017 allowed Chen and her team to demonstrate what this type of urban sensor network can accomplish. Together with colleagues from Harvard University (USA) and Germany's Ludwig-Maximilian University of Munich (LMU), the German Aerospace Center (DLR) and the Karlsruhe Institute of Technology (KIT), ▷

Picture credit: Andreas Heddergott/TUM

"What drives me in my work is the potential to improve the quality of air – and thus of people's lives"

Jia Chen



Greenhouse gas emissions in Germany (2016 estimates by the German Environment Agency, UBA)
Close to 906 million tons of greenhouse gases were emitted in Germany in 2016. The energy sector, including heat and power plants, as well as road traffic were the main sources. Emissions from industrial processes also contributed to the total amount of greenhouse gas emissions, as well as agriculture with mainly methane (CH_4) and nitrous oxide emissions. Germany's goal is to reduce emissions by 40 percent through 2020, compared to 1990 levels. The current level of reduction achieved is only 27.6 percent.

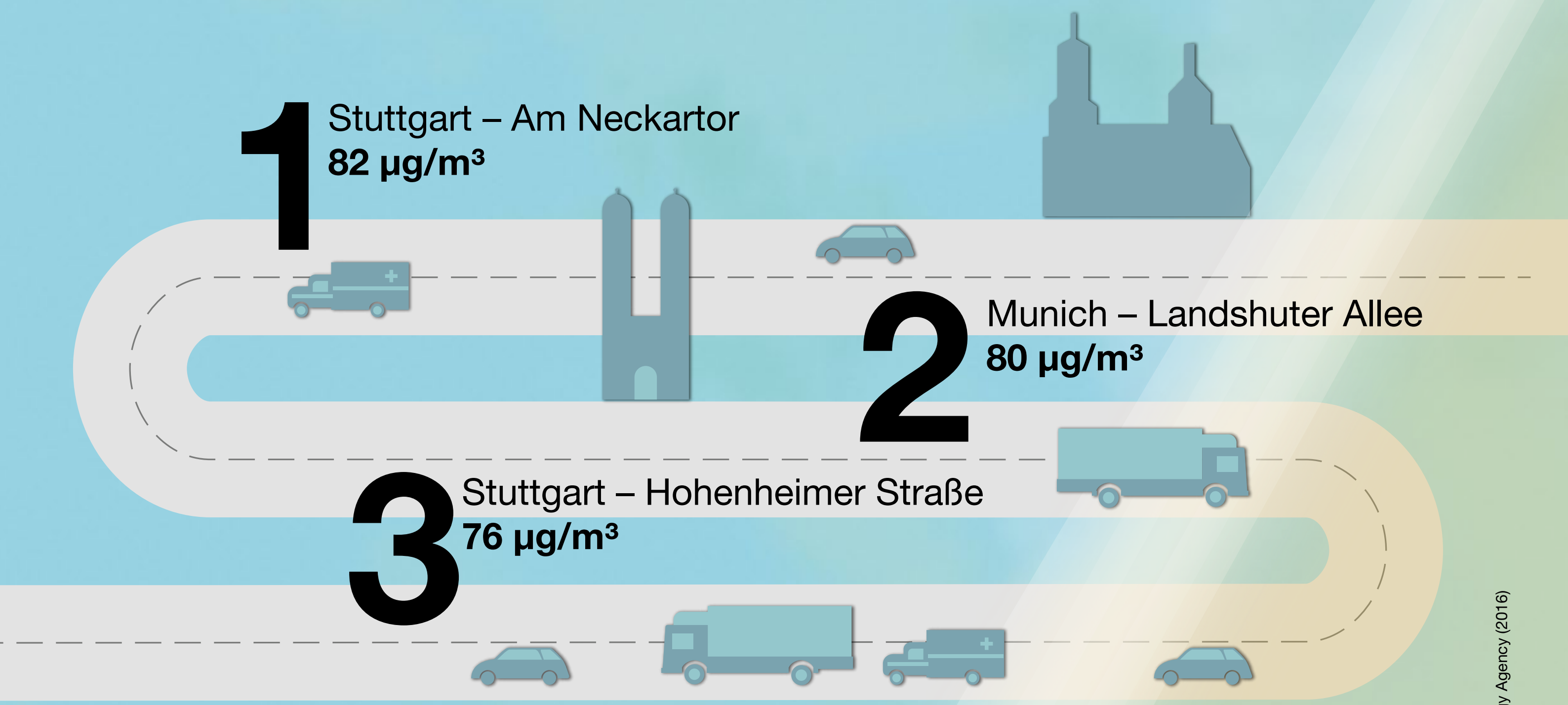
Picture credit: ediundsepp/TUM; Graphics: ediundsepp, Source: Federal Environmental Agency (UBA): Emissions data (March 2017)

Prof. Jia Chen

Always on the move

At the beginning of her presentations, Jia Chen likes to display a slide mapping her own mobility story. Her journey, stretching from China to the US, covers 180 degrees longitude: Jia Chen was born in Tianjin, "a small Chinese city with just twelve million inhabitants," she states with a smile. She started her studies in electrical engineering and information technology in Beijing and then transferred to Germany to continue studying at the Karlsruhe Institute of Technology (KIT), where she received her engineering degree in 2006. She completed her doctorate at TUM on the development of laser-based gas sensors.
In 2011, she moved on to Cambridge (USA), to pursue environmental research at Harvard University. Since 2015, Chen has been Professor of Environmental Sensing and Modeling at TUM. She is also a fellow of the TUM Institute for Advanced Study within the Rudolf Moessbauer Tenure Track program, and an associate at Harvard University.
"I started out by going west," acknowledges the 36-year-old. "But now I'm back in Munich, and this is a kind of geographical and research midpoint in my life. Munich's air quality index was 42 when I last checked – which is good, and as readers of Douglas Adams are well aware, also the answer to everything," shares the researcher with a wink.

Chen installed six measurement stations in and around Munich. The aim was to measure air pollution across time and space. The test included nitrogen oxide – a particularly hot topic in Germany following the diesel emissions scandal. When the analysis is completed, the results will be incorporated into an international measurement series comparing greenhouse gas emissions in major cities – research projects funded by the US Environmental Defense Fund (EDF) and the United Nations (UN).
Few people in Munich know as much about the city's greenhouse gas concentrations as Jia Chen. And although Munich may not top the list of cities with the cleanest air in the world, the researcher enjoys her time outdoors. "I spend an hour cycling from home to my downtown office and back every day," she confirms. "What drives me in my work is the potential to improve the quality of air – and thus of people's lives – around the globe." *Karsten Werth*



Nitrogen dioxide (NO_2) in 2016 (yearly average values in µg/m^3)
This pollutant is a serious problem in German cities. The threshold value of 40 micrograms per cubic meter (µg/m^3) on a yearly average was exceeded at about 57 percent of all the measuring stations located near major thoroughfares in 2016. The traffic intersections with the highest NO_2 concentrations were located in Stuttgart and Munich.

The world's urban areas produced more than 70 percent of global fossil-fuel CO_2 emissions, according to the International Energy Agency (2013). Prof. Jia Chen's aim is to develop accurate methods for measuring these urban carbon fluxes.

Graphics: ediundsepp, Source: Measurement data from the German federal states and the Federal Environmental Agency (UBA) (2016), International Energy Agency (2016)