

# Clean Air Challenge

Transport and heating solutions for better air quality



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InnoEnergy  
**Clean Air Challenge**  
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### Address by Jerzy Buzek

In his speech on the State of the European Union, Commission President, Jean-Claude Juncker spoke of the need for true unity by echoing the metaphor of Europe - East and West - breathing with both its lungs. Yet today, Europe still has a problem with breathing - literally.

Despite substantial improvement over the past decades, air pollution is still responsible for more than 400,000 premature deaths in Europe each year. Most Europeans living in cities continue to be exposed to air pollutants at levels deemed unsafe by the World Health Organisation. Be it from low-stack emissions, vehicles, households, or industry, power plants and agriculture, air pollution is the single largest environmental health risk in Europe.

The European Union recognizes this problem and is addressing it through a whole range of measures. In 2016, the European Parliament overwhelmingly voted for new lower limits of key air pollutants. This should significantly contribute to improved air quality across the continent and halve the related number of deaths by 2030. The Parliament is also working on vehicles emissions legislation and negotiating a reform of the Emissions Trading Scheme, where we are fighting to ensure free allowances for district heating. This should have a significant impact particularly in the cities that suffer from smog.

The EU has also been leading globally on clean energy technologies, streamlining research and innovation deployment across all energy sectors. We are currently improving the coherence and legibility of our

programmes and investment funds - not only at EU but also national, regional and local level - to further accelerate clean energy innovations. These can help us drastically improve the air quality across Europe. All these efforts must go hand in hand with education, growing public awareness as well as more effective public transportation, support schemes for low-emission solutions and improved efficiency, but also smarter design of our cities.

To be successful, we crucially need the support of experts, targeted studies and assessments of different options for our policies, programmes and schemes. This is particularly important as clean energy innovations are constantly changing the landscape and offer ever new possibilities. Here lies the significance of this publication prepared for InnoEnergy.

I trust that it will help guide our efforts at EU level - efforts which ultimately should allow Europe to breathe fully without struggling for air!

Jerzy Buzek

*Chairman of the European Parliament's Committee on Industry, Research and Energy,  
European Parliament's rapporteur on Accelerating Clean Energy Innovation*



# Executive summary



# Introduction – why should we concentrate on transport and heating?

**In Europe, air pollution is primarily a result of the combustion of hydrocarbons in road transport and heating.** In urban areas, emission of NO<sub>x</sub>, and NO<sub>2</sub> in particular are primarily the result of road transport. Secondly, emissions from household and commercial heating are known as “low-stack emissions” (when the point of origin is below 40m), and are caused largely by the use of low quality heating fuels, and old furnaces. Furthermore, low stack emissions are the primary contributor to the creation of excessive amounts of PM<sub>2.5</sub>, PM<sub>10</sub> and benzo(a)pyrene.

Although transport and heating represent a large potential for improvement in air quality, actual progress is limited by 4 major group of factors: technology, market incentives, public policies and awareness.

- 1. Technology:** despite fast technological progress, many innovative clean solutions in transport or heating have gained only a marginal market share. Usually, they either require scale of adoption and supplementing policies, or fundamental changes to habits on an individual level.
- 2. Market incentives:** demand and supply bottom-up mechanisms might lead to suboptimal outcomes in terms of real cost of air pollution. However, market activities represent individual preferences regarding consumption and production of goods, subject to feasible options. Thus, policymakers should be aware of these trade-offs.
- 3. Public policies:** planning and execution of public policies is affected by many factors that reduce their efficiency. In the context of smog, relevant issues include: lack of proper information available to policymakers, variety of political interests and need for international, regional and local cooperation between governments.
- 4. Awareness:** The negative impact of air pollution is well known, but the diffusion of this information to the general public is imperfect, which can result in higher pollution levels due to uninformed practices, and lower incentives for implementing new solutions, even such as public aid for implementing clean air solutions.

**The main source of smog also differs by region.** In Western Europe, for example, it originates primarily from transportation. By contrast, in Eastern Europe, the main source of smog is heating (and to a lesser extent, transportation). As a result, the smog problem in Europe may also be considered to be further complicated by regionalization.

## A call for action: smog costs the EU around 2.9% of its GDP every year

**Smog may account for as many as 1 in every 10 premature deaths in the world, and over 400,000 premature deaths in Europe every year.** It also affects the general quality of life on the continent by exacerbating, or even causing asthma and other respiratory problems. As with many other socio-economic issues, the elderly and the young are the most affected. With an increase of 100 units of PM<sub>10</sub> comes a reduction of average life expectancy of around 2.3 years among children by age 5.

**According to a study conducted by the European Commission, the total external costs related to the health effects of smog in the EU-28 are estimated to reach between €243 and €775 BLN by 2020.**<sup>1</sup> This figure is a product of premature deaths, rising healthcare bills, protracted illnesses, lower on-the-job productivity, and absences.

Although the European Commission’s projection notes a discernable downward trend in the economic burden of smog since 2010, the pace of improvement is predicted to level off in coming years. Hence, the BAU scenario (Business as Usual) is associated with a tacit acceptance of a

persistently high cost of externalities. This is further predicted to translate into a price tag ranging between €224 and €749 BLN by 2025 - only a 5-8% improvement on 2020.<sup>2</sup> **This means that the average value of the external costs between 2018-2025 amount to an astonishing €475 BLN - around 2.9% of forecasted average annual GDP for the EU-28 in the same period (assuming the middle estimate of externalities).**<sup>3</sup> Even when discussing the lower estimate, projected costs are still alarming – accounting for 1.37% of the average annual GDP.

## Potential innovative solutions

Following the conclusion regarding sources of air pollution, the technology tree below summarizes the mapped innovative solutions in the areas of transport and heating. It was constructed with the help of leading industry experts, and a survey among academic experts and practitioners was built upon the classification presented below.

Table 1. **Technology tree – key analysed groups and subgroups of solutions from transport and heating**

Level 0. Areas	Level 1. Groups of solutions	Level 2. Subgroups of solutions
Transport	Electromobility and alternative fuels	Alternative fuel vehicles
		Alternative transport solutions
		Infrastructure for alternative fuels
	Technologies supporting modal, organisational and behavioural shifts	Traffic optimisation
		Last mile solutions
		Increasing accessibility to low emission transport modes
Heating	Optimisation of combustion process	Optimisation of combustion process
	Energy efficiency	Insulation
		Efficient Energy management
	Grid, storage, and other integrating solutions	Smart Heat Grid
		Solar power efficiency
		Heat Storage
		Integrating solutions
	Heat generation	Heating from renewable energy
		Combined heat and power stations (CHPs)
		Heat pumps
		Energy recuperation
		4th and 5th generation networks
		Decentralised heat generation

Source: Analysis by Deloitte



## Our quantitative assessment

### Methodology and data source

Our general analytical approach consists of 4 major steps:

1. First, the relevant solutions for heating and transport were mapped and grouped. The result of this is the **technology tree** presented in Table 1.
2. Second, a **dedicated survey was conducted among a panel of experts in heating and transportation technologies**. The aim of the survey was to gather critical indicators for the potential impact of the given technologies' air pollution emissions and for investment attractiveness, as assessed from the market and technology readiness perspective.
3. In the next step, an urban database was constructed, covering 67 cities in 26 EU countries in order to measure **market potential using statistical methods**.
4. Lastly, a **quantitative model was created to generate a numerical assessment of the potential impact selected solutions will have on smog, and their potential market and technological attractiveness**. The model is based on our survey data and is a major tool used for giving investment recommendations.

It is important to note that quantitative results in this report represent the view and knowledge of the surveyed experts. Academics and practitioners were asked to provide the assessment on a chosen set of solutions until 2025. Hence, results as well as recommendations concern only mid-term perspective, which might be different than long-term outlook for selected solutions.

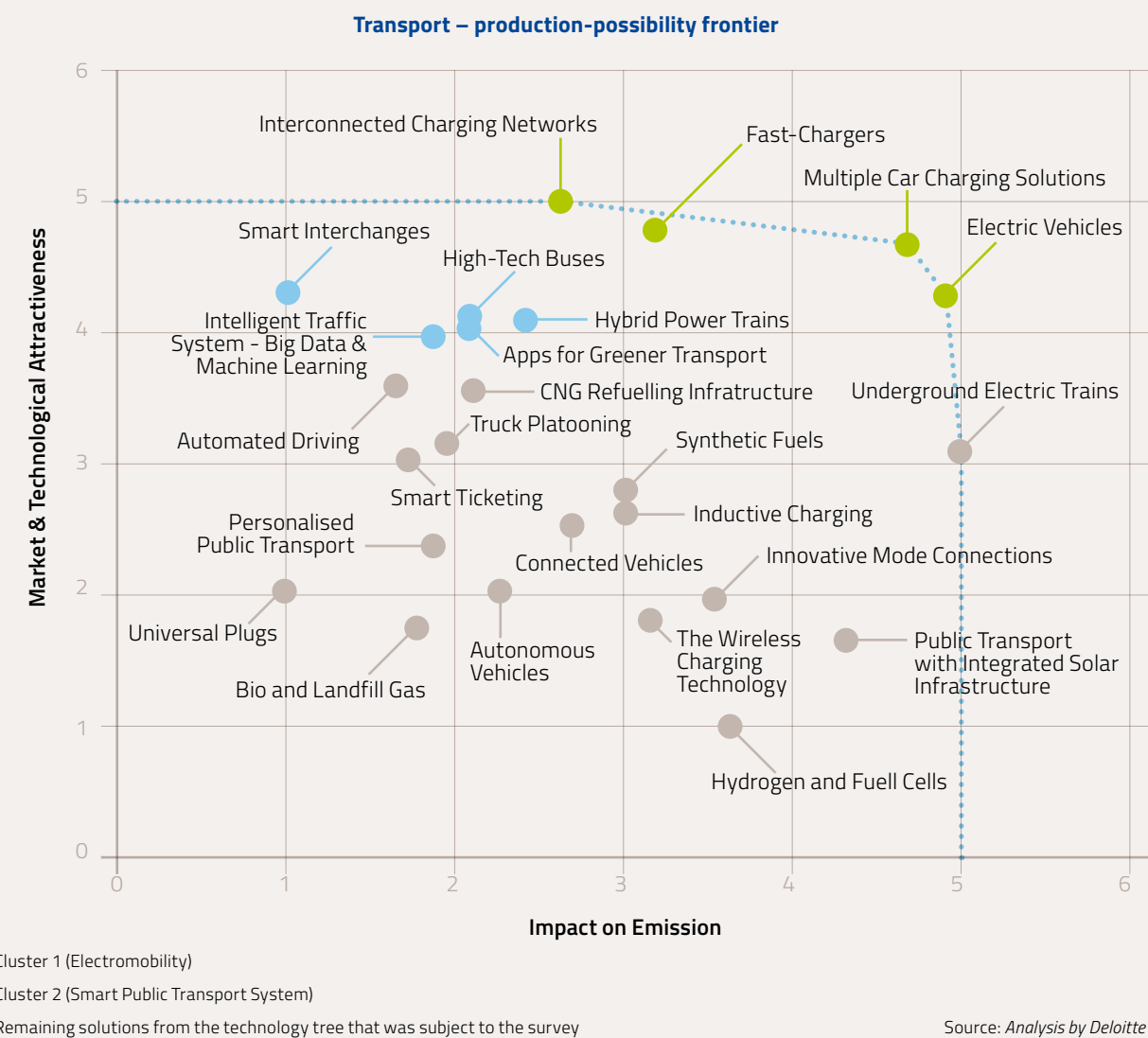
### Outcomes for Transport

According to our assessment, three solutions belonging to electromobility are characterized by an optimal combination of market and technological attractiveness as well as impact on smog. These are: **interconnected charging networks; multiple car charging solutions; electric vehicles**. Although fast-chargers are not defined as strictly efficient, since they do not lay on the graph on the production-possibility frontier, they are very close to the best solutions and should also be considered by prospective investors.



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Figure 1. **Model results for Transport – separate market (vertical axis) and technological attractiveness (horizontal axis) and impact on emission (bubble size)**

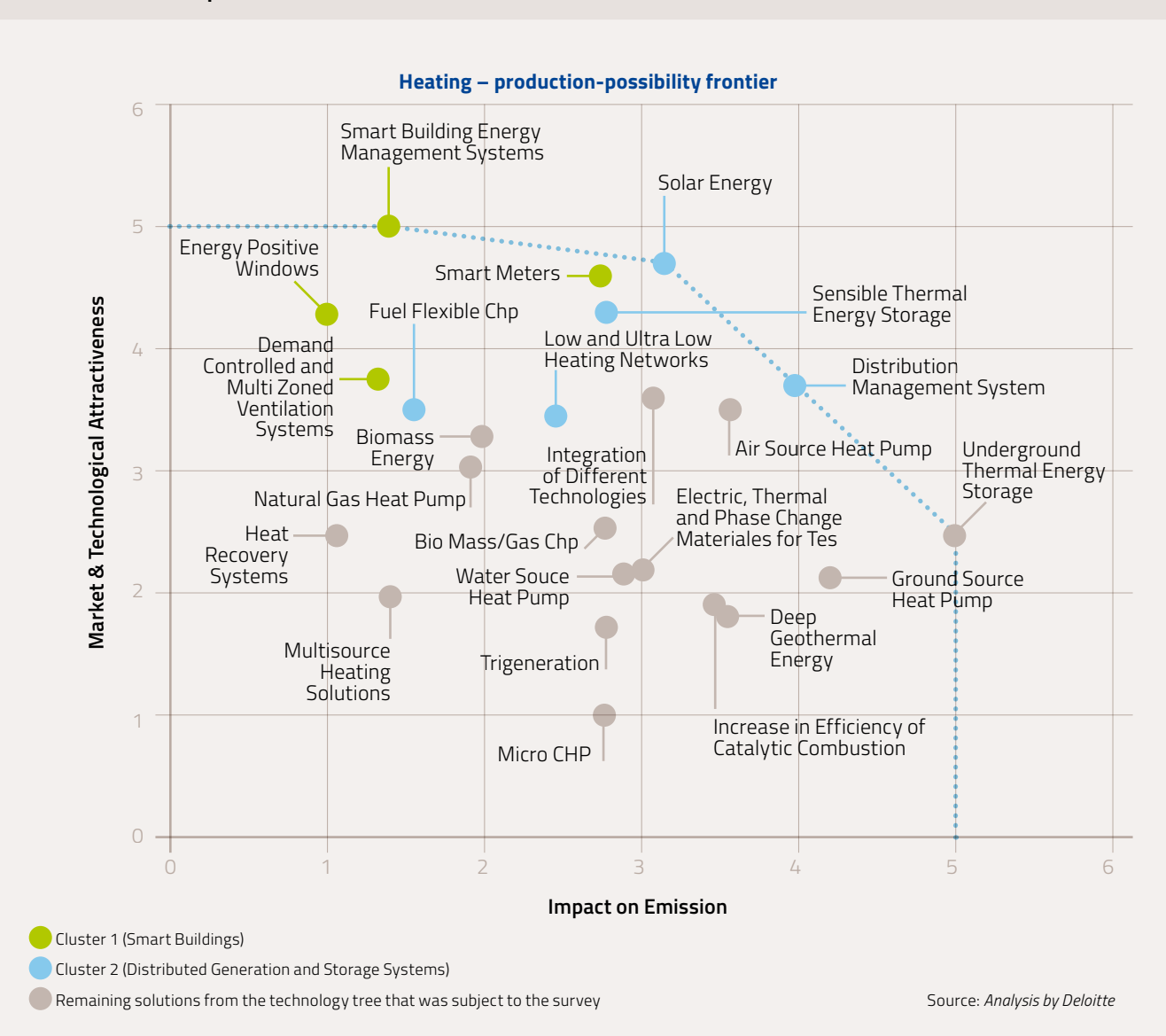


### Outcomes for Heating

Our results indicate that there are technologies on the production-possibility frontier from each area of heating: heat generation (solar thermal energy), heat storage (underground thermal energy storage) and energy efficiency (smart building energy management systems as well as distribution management systems). Contrary to the transport sector, there is no single dominating cluster.

Relatively close to the frontier and thus included in the clusters are the following: **energy positive windows, smart meters and sensible thermal energy storage**. From an investment point of view, we can also add to the defined clusters items like: **demand-controlled and multi-zoned ventilation systems, fuel flexible CHP, low and ultra-low heating networks**. According to our survey and quantitative model, weaker performance of these selected items is related to relatively low technological readiness or average market perspective

Figure 2. **Model results for Heating – production-possibility frontier, combined market and technological attractiveness (vertical axis) and impact on emission (horizontal axis)**



## Conclusions and recommendations

**Within transport sector, creation of the better ecosystem for electromobility is the best investment opportunity.** This holds for the market, technological and emission reductions point of view. The most promising investment areas include building the infrastructure for electromobility (multiple car charging solutions, interconnected charging networks, fast chargers), and producing electric vehicles.

**Small Public Transport System Cluster is a valuable supplement to investment portfolio that allows risk diversification as well as serving very important markets.** Moreover, there are no noticeable trade-offs between market and technological attractiveness and environmental value.

**With respect to heating sector, the most promising solutions might be attributed to the Small Public Transport System Cluster.** Particularly attractive for investors are the following: solar

thermal energy, smart building energy management systems as well as distribution management systems. Underground thermal energy storage is the most efficient for investors that maximize potential impact on smog, though possibility of delivering it is a subject to significant technological risk.

**We formulate four high-level policy recommendations** that summarize lessons learned from the topic and more general conclusions from economic and social research. Later on, policy recommendations for clusters aim to correspond with specific barriers and challenges to innovation adaption and new investments.

### Green and sustainable growth as an overarching goal

Green growth should be key for both the private and public sector as it increases the quality of life for current and future generations. This requires good coordination across all environmental policies, thus linking them with the current socio-economic context.

### Sufficient room for markets with smart interventions

A smart balance of market-based instruments and a top-down approach is needed to address potential trade-offs between securing important goods like economic welfare, mobility, air quality, health, ecosystems, affordable housing, cheap energy etc.

### Education and social awareness as a foundation for successful adoption of green innovations

Investing in education and raising social awareness should not only be one of the priorities for the public agenda, but also a responsibility of businesses and NGOs. Air quality policies should be seen and promoted within the wider socio-economic spectrum so as to ensure that the measures implemented are adequate.

### Enhanced statistical framework and new data sources to induce innovative activities

Strengthening statistical capacity is fundamental for improving the process of planning and executing private investments as well as evidence-based policies. Decentralized data sources provided by sensors, apps, and intelligent devices might largely reduce information asymmetry and, in effect, boost innovation and investments.

## Potential impact of recommended solutions on the EU-28 economy: a scenario simulation

**The simulation presented here is based on the survey of potential emissions impacts, as well as estimates of the external costs of air pollution, as made by the European Commission.<sup>4</sup>** In this report, we recommend to focus on investments in 4 key clusters:

1. Electromobility
2. Smart public transport systems
3. Smart buildings
4. Distributed generation and storage

A joint impact assessment of abovementioned clusters was performed with using two scenarios regarding the pace of market growth and technological development:

**“Conservative 10% in 2025” Scenario** (10% of average market share in 2025)

**“Ambitious 25% in 2025” Scenario** (25% of average market share in 2025)

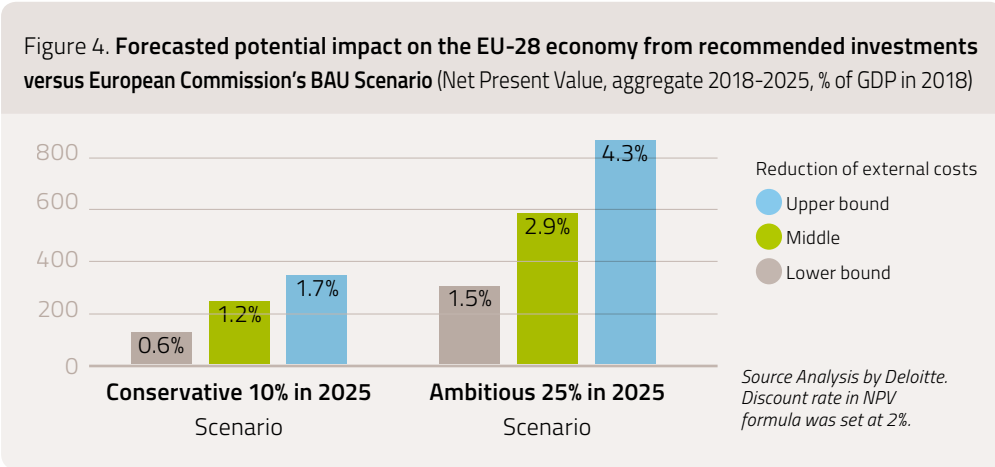
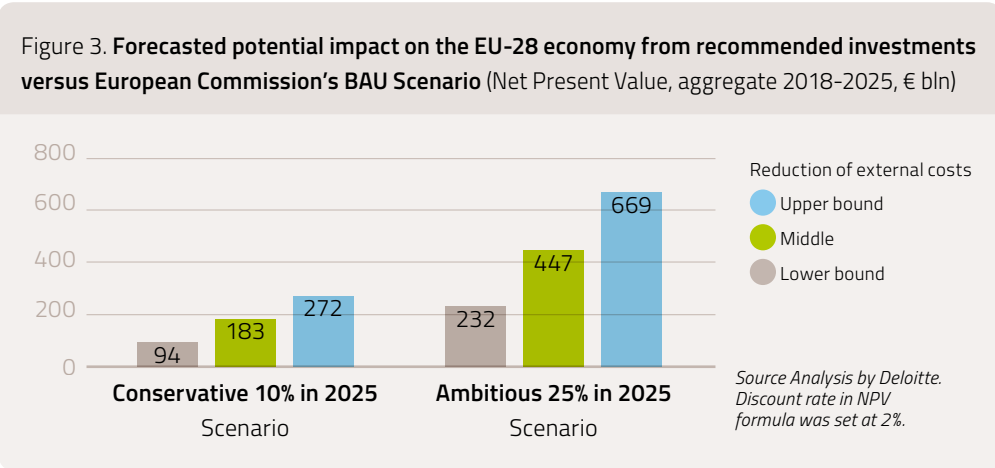
Both scenarios assume that market penetration for all solutions within the 4 clusters begins at 1% in 2018. Then, this share grows at a constant pace so as to attain the respective target values – 10% or 25%.

**The key inputs for these simulations were provided by a group of surveyed experts, who assessed the potential impacts on air pollution for given solutions.** Hence, it was possible to



estimate what could be the impact of X% resulting from the predominant market penetration of solution Y, as compared to a baseline solution.

Further assumptions for the model were derived from the abovementioned European Commission's elaboration on the external costs of air pollution. This was in turn supplemented by data on the unit cost of air pollutants, and on the sources of pollutants provided by the European Environmental Agency.<sup>5</sup>



Finally, we are able to present **6 outcomes relating to the potential impact on the European economy as a result of the adoption of greener solutions. Much of the savings can be interpreted as reduced health-related expenses in relation to the total external costs of air pollution.** These 6 values come from crossing 2 Scenarios related to market and technological developments, as well as 3 estimates of the external costs (upper and lower provided by the European Commission, and one equal to their average, or "middle of the range"). The main advantage of this approach is that it enables us to capture 2 major sources of uncertainty – namely the proper estimate for external costs, as well as the forward potential for both market and technological disruptions.

**According to our simulated conservative Scenario, European citizens might be able to pocket an extra €183 BLN between 2018 and 2025 - the an equivalent of 1.2% of the forecasted GDP in the EU-28 in 2018.** This result is a combination of the "Conservative 10% in 2025" scenario in terms of investments and supporting polices, as well as the middle value of estimated external costs. It should be underlined that even the lowest outcome means a non-negligible net effect – a reality which drives our call for comprehensive anti-smog action. What is more is that this course should have the added benefit of boosting both investment and innovation in the transport and heating sectors.







# Objective of the study

The objective of this work is to perform a broad study of the available solutions which might be employed so as to help alleviate the existing smog concentrations in Europe – particularly felt in cities, industrialized areas and transport hubs. The results of this analysis will serve to guide InnoEnergy in its role as an institutional investor which supports innovative projects, and especially start ups, bearing both positive and tangible environmental impacts. Recommendations are formulated based upon the quantitative assessment of available technological, financial and social solutions in the fields of transport and heating. Behind this is an analytical approach, which is applied for impact assessment. This methodology is advantageous, as it takes into account numerous economic, social, and relevant structural factors, all on an urban level.

By building better understanding of clean air related innovation landscape, this study should allow InnoEnergy to identify and pursue impactful investments focused on one of the major modern day energy-related challenges. This will in turn facilitate a transition towards a company driven by its socio-economic impact, rather than primarily financial objectives. It will also create opportunities to enhance InnoEnergy network and facilitate engaging key stakeholders beyond the traditional business community, such as cities, local energy communities and NGOs.

Another important target is to spur the public debate surrounding air quality issues, particularly those revolving around the high, compound socio-economic costs of current pollution levels. Due to problems such as lack of public awareness, and informational barriers, the negative impacts of smog and its social burdens are generally not well understood by the population at large. This problem has at least two main negative consequences: firstly, this situation might result in higher pollution levels through uninformed practices, and secondly, there are likely to be lower incentives for implementing new solutions in societies where awareness is lower, thus often exacerbating the first consequence.

From all of this, we may gather that any campaign to combat smog might only be successfully waged in three parts. Namely, these are: informed, highly strategic investment decisions (particularly vis-à-vis specific transport and heating solutions), strong incentives as well as reward mechanisms for innovative solutions, and finally broad social support brought about by higher awareness and engagement in solving the problem. The latter conditions are also prerequisites for more efficient market and regulatory incentives to be tailored in the long-run, thus enabling the reduction of high uncertainty, which generally accompanies novelty.





# Context

The quality of our air has been a growing concern since at least the 18<sup>th</sup> century – the issue is not new. With the introduction of the combustion engine during the Industrial Revolution, we have increasingly depended on fossil fuels to power our economies. With both the intensive growth in established economies, and extensive growth in developing countries, smog continues to strangle our cities, having both direct and indirect impacts on health, society and productivity.



The overarching issue can be divided along the lines of its two major contributors – namely transportation and heating. Emissions resulting from these sources are projected to increase in the coming decades, a concerning prospect, as the OECD predicts that every year, anthropogenic pollutants could result in up to 9 million premature deaths globally. Materially, this means that air quality will cost us the equivalent of around 1% the global GDP by 2060.<sup>6</sup> Although these consequences are known and well researched, both the complexity of the issue and drastic nature of the measures to be taken make the adoption of solutions an onerous process. This being said, the fundamental issue is that of keeping our planet habitable, and as such it is imperative that we actively seek to improve the quality of air which we breathe.

## Main types and sources of smog and air pollution

Within the context of this report, we shall focus exclusively on man-made, outdoor air pollution, with special attention given to smog. Smog is of particular interest owing to the bio-chemical changes that it brings about, and that these have adverse effects on all living and inanimate entities – people, crops, property, and the natural environment.

### Natural sources of pollution

While it is possible to reduce man-made pollution, there are many natural sources of air pollution which remain outside of our control. These include volcanoes, dust storms, biological decay, wildfires and lightning strikes. It is difficult to calculate the exact amount of air pollution released by natural sources, but they

certainly play a significant role. For instance, NO<sub>x</sub> released from natural sources is estimated at between 20 to 90 million tonnes per year, versus global man-made NOx emission sitting at around 24 million tonnes<sup>7</sup>.

### What is outdoor air pollution?

Air pollution is just like any other and all changes to the levels of air’s natural constituents, such that they have a negative effect on our physical environment. This might entail a change in the balance of the environmental make-up or the introduction of harmful gases, dust or particulates.

Although many substances cause impure air, this report focuses on five of them – namely **NO<sub>x</sub>**, **SO<sub>x</sub>**, **BaP**, **PM<sub>10</sub>** (particulate matter less than 10 µm), **PM<sub>2.5</sub>** (particulate matter less than 2.5 µm), and **CO<sub>2</sub>**, with all except CO<sub>2</sub> being associated directly with smog formation. Because the report focuses on substances which have the greatest influence on smog formation, carbon dioxide is addressed secondly. The reasoning behind this is that CO<sub>2</sub> is a long-life greenhouse gas mainly associated with climate change, which is a parallel problem. This being said, many of the solutions aimed at air pollution can have side benefits vis-à-vis climate change mitigation. Table 2 shows the pollutants reviewed in this report and their main sources in Europe.

Table 2: **Major types of man-made air pollution and main sources (EU-28)<sup>8</sup>**

Type	Abb	Pollutant	Top sectoral emitters in EU-28 <sup>9</sup>	Urban population in EU-28 exposed to concentrations above the maximum permitted level
Gas	NO <sub>x</sub>	Nitrogen oxides	<b>Road transport (39%)</b> Energy production and distribution (19%) <b>Heating (14%)</b>	<b>9%</b> (NO <sub>2</sub> )
	SO <sub>x</sub>	Sulphur oxides	Energy production and distribution (59%) Energy use in industry (19%) <b>Heating (13%)</b>	<b>&lt;1%</b> (SO <sub>2</sub> )
	BaP	Benzo(a)pyrene	<b>Heating (75%)</b> Agriculture (12%)	<b>25%</b>
	CO <sub>2</sub>	Carbon dioxide	<b>Heating (42%)</b> Energy production and distribution (29%) <b>Road transport (19%)</b>	n/a
Solid or liquid	PM <sub>10</sub>	Particulate matter	<b>Heating (42%)</b> Industrial processes and product use (17%) Agriculture (15%)	<b>20%</b>
	PM <sub>2.5</sub>	Particulate matter	<b>Heating (57%)</b> <b>Road transport (11%)</b>	<b>8%</b>

As we can see in Table 2, the four main air pollutants which affect European cities are (in the order of increasing exposure): Benzo(a)pyrene, coarser particulates (PM<sub>10</sub>), nitrogen oxides (NO<sub>x</sub>), and finer particulates (PM<sub>2.5</sub>).

**In Europe, air pollution is primarily a result of the combustion of hydrocarbons in road transport and heating.** Emissions of NO<sub>x</sub> and NO<sub>2</sub> in particular are the primary result of road transport. Emissions from household and commercial heating are called “low-stack emissions” (when the point of origin is below 40m), and are caused by the use of low quality heating fuels, and old furnaces. Low stack emissions predominantly contribute to the creation of excessive amounts of PM<sub>2.5</sub>, PM<sub>10</sub> and benzo(a)pyrene.

### Smog as a type of air pollution

Smog is a type of air pollution, as it represents a persistent manifestation of a change in the atmosphere in line with the definition previously laid out.

There are two ways that the emission of pollutants form smog – they can either be emitted directly to the atmosphere (primary), or formed by the interaction of two or more primary pollutants already in air (secondary). It should be noted that secondary pollution is just as harmful to humans as its primary counterpart.

Table 3. **Primary and secondary sources of air pollutants**

Sources of air pollutants	
Primary	Secondary
PM, SO <sub>x</sub> , NO <sub>x</sub> , BaP	PM, O <sub>3</sub> and NO <sub>2</sub>

One type of smog which represents a manifestation of primary pollution is a **sulphurous smog**, which is the result of a high concentration of SO<sub>2</sub> and caused by the use of fossil fuels, particularly coal. This smog – the so-called “London smog” – intensifies with humidity and high concentrations of suspended particulate matter in the air. Even though, over the years this problem has been much reduced because of technical improvement and strict legislation, there are still polluted spots where such smog occurs, especially in Central and Eastern Europe.

A product of secondary pollution – known as the “Los Angeles smog” – is a **photochemical smog**, which occurs mostly in urban areas that have a large number of cars. This type is intensified by high insolation together with windless conditions.

Socio-economic impacts

One of the main reasons why smog is a hard issue to tackle is cost allocation. The problem is that the monetary assessments associated with the emission of air pollution do not fully capture the associated cost. The polluter – a user of a car or a heat source – makes decisions based on their individual benefits and costs, and does not consider the effects to those harmed by the pollution. These effects are what economists call ‘externalities.’

**Smog has a number of socio-economic consequences, both direct and indirect.** A large part of the existing body of research and literature on the subject of smog concentrates on the direct consequences of air pollution, seeking to quantify the effects of this phenomenon by focusing on the number of premature deaths that it causes. It must indeed be said that this is the major socio-economic effect of smog, as even 1 in every 10 premature deaths in the world might be attributable to poor air quality.<sup>10</sup> As with many other socio-economic issues, the elderly and the young are particularly vulnerable – with an increase of 100 units of PM<sub>10</sub> reducing average life expectancy by 2.3 years among children by age 5.<sup>11</sup> Conversely, evidence from China suggests that a 10% decrease in PM<sub>10</sub> concentration may reduce the monthly mortality rate by 8%.<sup>12</sup>

The direct socio-economic benefits of regulations on air control might be even 4 times higher than costs

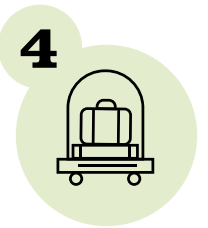
The U.S. Office of Management and Budget (OMB) estimated the economic effects of laws regarding air quality that were passed between 2004 and 2014. According to their study, the American economy saved between \$157 BLN and \$777 BLN (based on 2010 prices) as a result of lower exposure to fine particulate matter, and the consequential fall of healthcare expenditure. The cost of implemented regulations was assessed between \$37 BLN and \$44 BLN, representing less than 25% of the benefits. It is worth noting that in the study, the OMB only took into account the direct effects, namely those related to human health. Adding up indirect costs like damage to the biosphere and distorted labour markets would further increase the ratio between benefits and costs.<sup>13</sup>

**Air pollution has many short-term and long-term consequences other than premature deaths in the affected societies** – in fact, smog has a significant impact on both regional and national economies. This is aggravated by the fact that cities are disproportionately affected by poor air quality, but also remain concentrations of the most important drivers of economic growth – namely high-skilled labour / human capital, specific capital goods, as well as extensive technology pools.

The list of indirect effects of smog includes



**Distorted spatial or sectoral allocation of labour in the economy**, as many people might be reluctant to work in cities where air quality is poor. **A consequence of this is lower economic productivity** from both the strains of a “pure allocation” effect and a weaker “pooling” effect of labour.



**Lower incomes as well as a lower number of jobs in tourism and recreation** – unappealing locations tend not to attract visitors, or qualified professionals who might establish themselves within societies. The former brings with them a net import of capital, and the latter bring expertise as well as higher wages.



**Distorted competition dynamic, which in turn hampers “creative destruction”.** As a consequence, some inefficient local firms are “protected” from external competition, which in the long-term reduces potential GDP growth. This differs from the following point as the issue is systemic rather than one which affects individual development or decision making.



**Lower value of real estate and some productive assets, translating into reduced income from rents or investment.** Real estate has long been considered a fundamental, relatively ‘safe’ investment. Cities in which property prices rise and rents are high become attractive venues for capital investment, leading to multiplier effects. For this reason, the attractiveness of home ownership is often a successful part of a cities ‘brand.’



**Drag on human capital growth**, resulting from extensive negative health impacts, resulting in elevated sick leaves and persistent diseases, as well as lower levels of education. A negative effect on human capital is directly correlated with lower productivity and GDP growth.

The Great London Smog of 1952 and the long-lasting effects

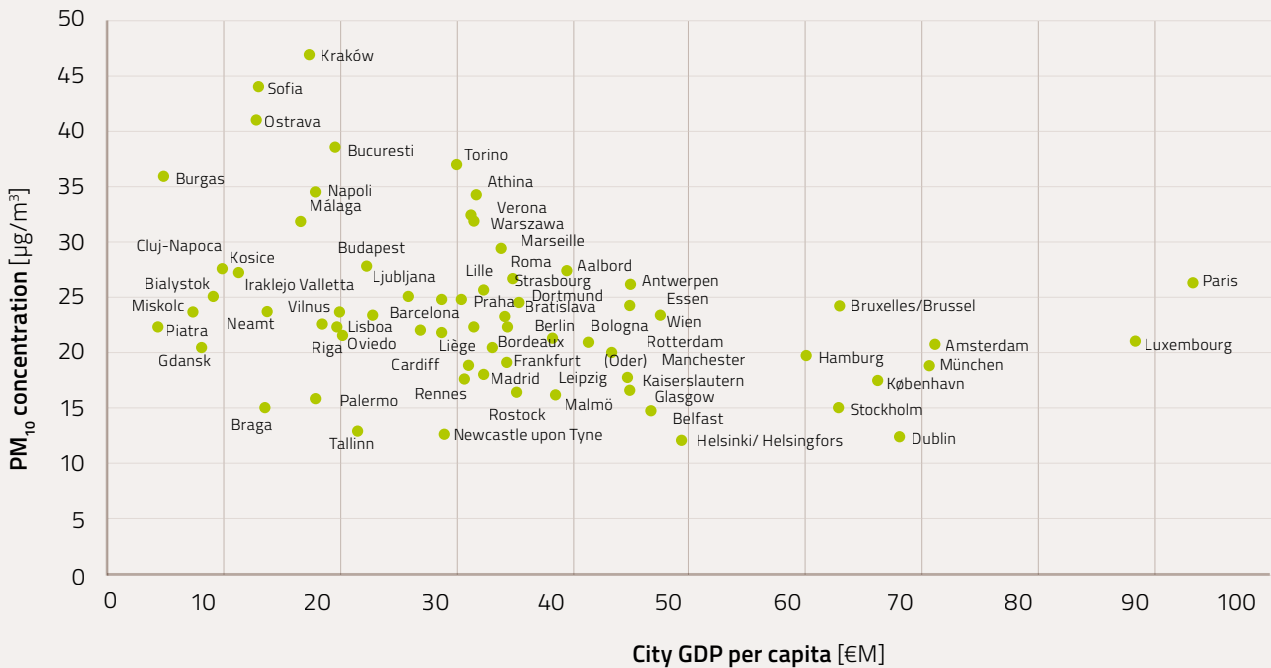
Of particular concern is that many of the problems associated with smog are long-lasting. One of the most striking case studies of this reality is to be found in an empirical study of the Great London Smog of 1952. Although inhabitants were exposed to this hazard for only 4 days, after 60 years, the size of the surviving cohort (population by age) shrank by 2% as a direct result of the extreme level of pollution (not counting expected attrition). Moreover, those who had not died tended to suffer from persistent, premature diseases – leading to reduced employment opportunities, working hours as well as skills & knowledge. Moving away from extreme cases, the benefits of improving air

quality are even observable in contexts where levels of pollution are moderate or well below the level set by the WHO. One such example of this phenomenon can be found in Dunkirk (France), where in 2009, a major oil refinery was shuttered, resulting in a reduction in levels of sulphur dioxide (SO<sub>2</sub>) by an average of 5 micrograms per cubic meter. Of further interest are the socio-economic benefits, such as reduced time spent in hospital adding an estimated €1.4 MLN to the public coffers on an annual basis. Moreover, local real estate prices abruptly grew by 5% in direct chronological correlation to the closure, representing an extra EUR 7,500 in the pocket of each seller (on average).

As was intimated in the points presented earlier, although air pollution directly affects workers and their families, it is also detrimental to investment - particularly private. For example, a number of foreign companies operating in China have had to resort to offering an extra “pollution premium” in order to attract qualified workers, resulting in additional overhead, and a less attractive operating environment.<sup>14</sup> With regard to tourism, parallels can be traced to the growing for so-called “smog insurance” with compensation based on the recorded air pollution during the travel.<sup>15</sup> This makes the burden on the visitor more financially onerous, resulting in loss not only in travel spending, but an overall opportunity cost with regard to those who chose to avoid destinations all together.

As we can see, the list of externalities caused by smog is long. The main problem with externalities is that letting the market dictate terms may not lead to a situation in which the well-being of all members of society (especially the most vulnerable) is maximized, let alone considered. Unless the costs or benefits are covered at the source, market outcomes can lead to the overproduction of negative externalities or underproduction of positive ones.

Figure 5. Annual average concentration of PM<sub>10</sub> and GDP per capita in cities<sup>16</sup>



Evidence suggest that there is only a weak relationship between GDP per capita and smog prevalence in European cities (Figure 5). Indeed, we can observe that cities with a comparable level of income might offer substantially different air quality to its inhabitants. **It leads to the hypothesis that current level of GDP per capita in Europe does not play a dominant role in explaining air pollution patterns, though it cannot be neglected.**

Among large cities, the most polluted are located in Central Europe (Cracow, Ostrava), the Balkans (Bucharest, Sofia) and along the Mediterranean Sea (Athens, Malaga and Napoli). Although it would appear that this is quite a heterogeneous set, the common underlayer is that these municipalities are located in less developed parts of the EU, which are actively attempting to either sustain (Central Europe, Balkans) or restore (Mediterranean) a parity of GDP per capita with the most advanced constituent countries.

Taking into account the points raised above, **it is fair to assert that air pollution is likely slowing the pace of integration of nations within the EU, both in terms of GDP per capita and a broader quality of life.**<sup>17</sup>

Major challenge: reducing emissions from heating and transport

In the previous sections, we discovered that there is no question that air pollution has unintended consequences on society and the economy, and that the problem is further exacerbated by the difficulty of unregulated markets to achieve optimal levels. It might now be worth having a look at what the pros and cons of some of the tangible solutions might be.

**Technological solutions to address air pollution exist**, such as sustainable transport in cities, central heating networks, clean household fuels, greater implementation of renewable energies, as well as industrial emissions reductions. **Tangibly, there is a precedent of cities overcoming the**



**issue of excessive air pollution without sacrificing economic competitiveness.** Other than the classic cases of Scandinavian cities (with decades-long commitments to clean air policies, and a multifaceted framework of policy instruments), there are also more recent examples. For example, New York (which is not known for its clean air), managed to reduce SO<sub>2</sub> levels by 67% across the city within a decade through state and local cooperation, as well as dedicated programmes.<sup>18</sup> This being said, although positive case studies exist, air pollution and smog still remain a major challenge, and it is perhaps worth asking why that is.

**First of all, there is no silver bullet.** This is due to the fact that air pollution is a very versatile problem. It has many causes, with heating and transport industries being merely the primary pollutants. It must be kept in mind that smog can have various compositions as well as forms, depending on the source, and even geography. From this, one may see that air quality is at once a complex and regionalised issue, with no ‘one-size-fits-all’ solution.

**Another major hurdle is that society can be unaware of the problem or underestimate its scale.**

For example, even though Poland has a serious air pollution issue, with BaP concentration in Polish cities and towns several times above the acceptable limits, two years ago around 60% of people in Poland believed that the air they breathe in is of good or very good quality.<sup>19</sup> Interestingly, similar results were observed in the UK, where inaction was to be found in many affected urban centres.<sup>20</sup>

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## Public awareness fostering green growth and air quality

The negative impacts of air pollution on both societies and economies are well known, but the diffusion of this information to the general public is imperfect, despite increasing access to information in the last decades<sup>21</sup>. What is more is that there is no extensive body of research that explicitly confirms the intuitive relationship between an increase in social awareness and an improvement in air quality.

One of the few attempts to verify this relationship was a study conducted jointly by the London School of Economics and Political Science (LSE), Local Governments for Sustainability (ICLEI) and the Global Green Growth Institute (GGGI).<sup>22</sup> This study included a global survey of 90 cities which aimed at identifying the main factors which trigger an adoption of green objectives, including air quality improvement. The survey shows that the strongest driver for the growth of air quality standards is environmental awareness.

It is also pointed out that public awareness depends on the education level,<sup>23</sup> income,<sup>24</sup> consumer behaviour,<sup>25</sup> and that there is a significant role to play for non-governmental organisations. In Poland, Polish Smog Alert<sup>26</sup> (Polski Alarm Smogowy) is a leader in sharing information about the sources of smog, the effects of air pollution, as well as the green growth way. Key operations of Polish Smog Alert include the live monitoring of air quality and publicizing when the daily concentrations of pollutants are exceeded. To increase their impact, PSA cooperates with around 200 volunteers engaged in anti-smog activities. Beyond that, Polish Smog Alert activists work together with local officials, doctors, the academic community and local communities so as to ensure that their approach is comprehensive, targeted at the right awareness issues, and up to date with scientific research.

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**Available solutions have two defining features: they either require scale of transformation, or require fundamental changes to habits on an individual level.** With changes of scale come big investment commitments that tighten both municipal and national budgets. Accompanying this approach, conventional command and control policies such as vehicle standards or banning coal / waste use for residential heating hurt household finances, breeding resistance to change among the citizenry. This in turn means that tackling smog becomes a **politically sensitive subject** which, when combined with a limited public awareness, can prove unpopular and draining to the approval ratings of politicians attempting to effectuate positive change.

Troublingly, along with the growing global population, increasing levels of urbanisation and prosperity, **the pressures on air quality in cities will continue to grow, despite them already being a critical problem.** This in turn means that the **efforts to tackle this problem are imperative, not a luxury.**





An aerial photograph of a city, likely London, showing a dense urban landscape with numerous buildings. In the foreground, a large industrial complex with several tall smokestacks is visible. One smokestack is emitting a thick, dark plume of smoke that rises into the sky. The city is situated along a river, and the overall atmosphere is hazy, suggesting air pollution. The image is split vertically by a thin black line.

# Current situation and policy framework

Increasingly evident consequences of **climate change** exacerbate the effects of air pollution, leading to both more frequent, and longer lasting smog. Under the pressures of **suburbanisation**, **urban poverty**, and the growing **societal impetus for clean air** now, more than ever before, affordable and scalable technological solutions are needed.



Encouragingly, the **4<sup>th</sup> Industrial Revolution** has brought with it many promising innovations. This being said, **economic uncertainty, low levels of projected growth, and political instability** create considerable challenges for finding investors who are willing to devote capital to operationalise these ideas. On the other hand, one may observe some signs of positive change. These include **an increasing demand for clean air**, a reduced affordability of fossil fuels, and the most promising observable trend – the increasing willingness of governments across the globe to drive action through targeted policy making. Unfortunately, the latter trend has been hampered to some extent by recent political instability and a move to short-term perspective decision making and electorate pleasing.

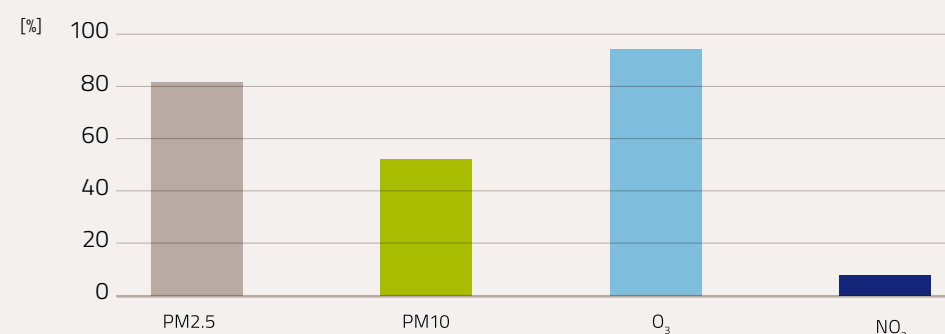
As encouraging as some trends may seem, cutting air pollution will require the widespread mobilization of public and private financial resources, as well as changes in current energy policy. There is a growing need for the adoption of financial instruments that channel capital to projects involving energy efficiency, clean air technologies, the energy conservation sector, and for leveraging more investment in the environmental and social area.

## Current situation and outlook in global pollution hotspots

Available statistics do not paint an optimistic picture for air quality in relation to the world's urban populations. According to the WHO, the level of urban air pollution increased by 8% worldwide between 2008 and 2013. As was previously mentioned, over 80% of people living in the urban areas monitored in the study were exposed to levels of pollutant which exceed WHO limits – but if we look at modelled data, the number goes up to 92%.

Despite the fact that since 1990 there has been a decrease in industrial pollution and greenhouse gas emissions, primarily thanks to EU policies and investment, a significant number of Europeans – mainly in Eastern Europe – still breathe air with unacceptable concentrations of hazardous substances. In fact, 98% of Europeans living in cities are exposed to unsafe levels of air pollutants (Figure 6), primarily ozone (96%), fine particulates (82%), and benzo(a)pyrene (approx. 90%).<sup>27</sup>

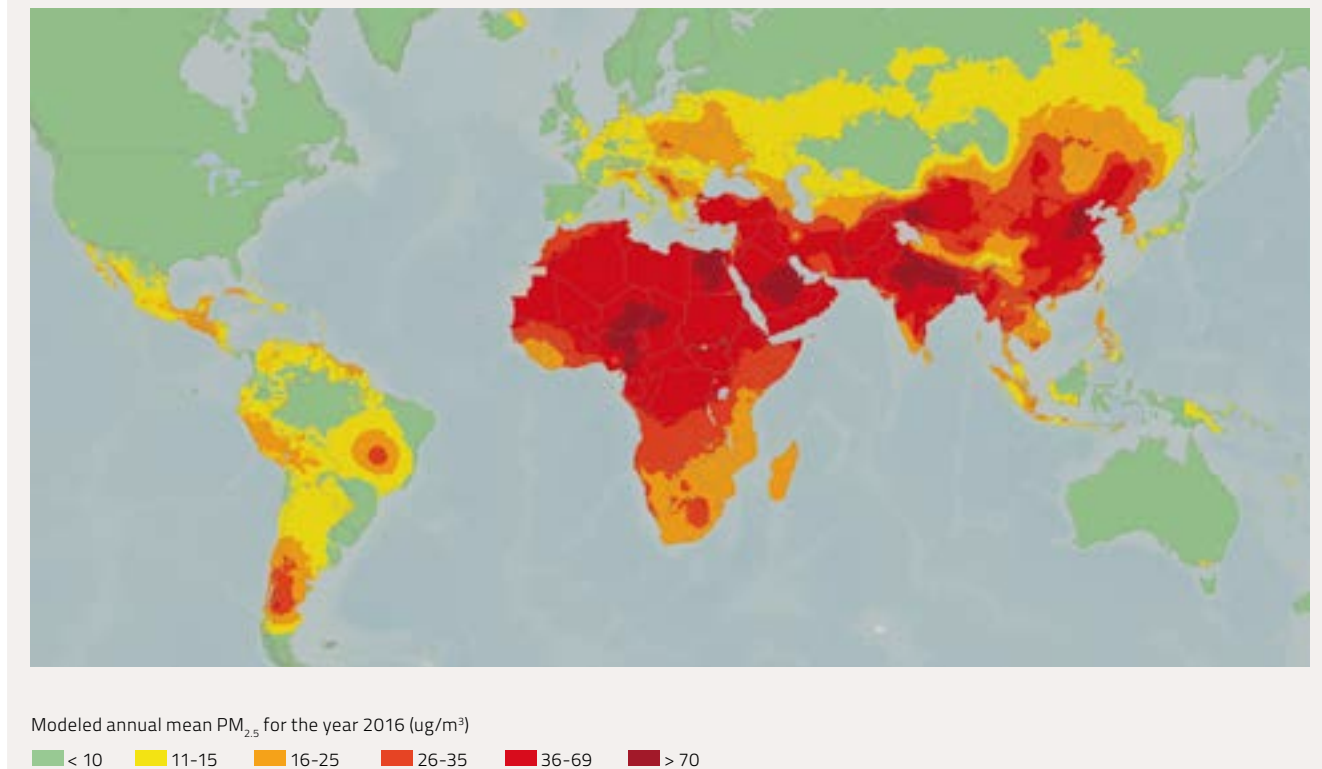
Figure 6. **Percentage of EU urban population exposed to air pollutant concentrations above WHO air quality guidelines**<sup>28</sup>



It is worth noting that the fact that levels have been exceeded are only half of the issue – the factor by which these levels were exceeded might even be described as ‘startling.’ The highest levels of such airborne toxins were observed in low-and middle-income countries

in the Eastern Mediterranean and South-East Asia (Figure 7). Conversely, levels of urban air pollution were lowest in high-income countries, with lower levels most prevalent in Western Europe, the Americas, and the Western Pacific Region.

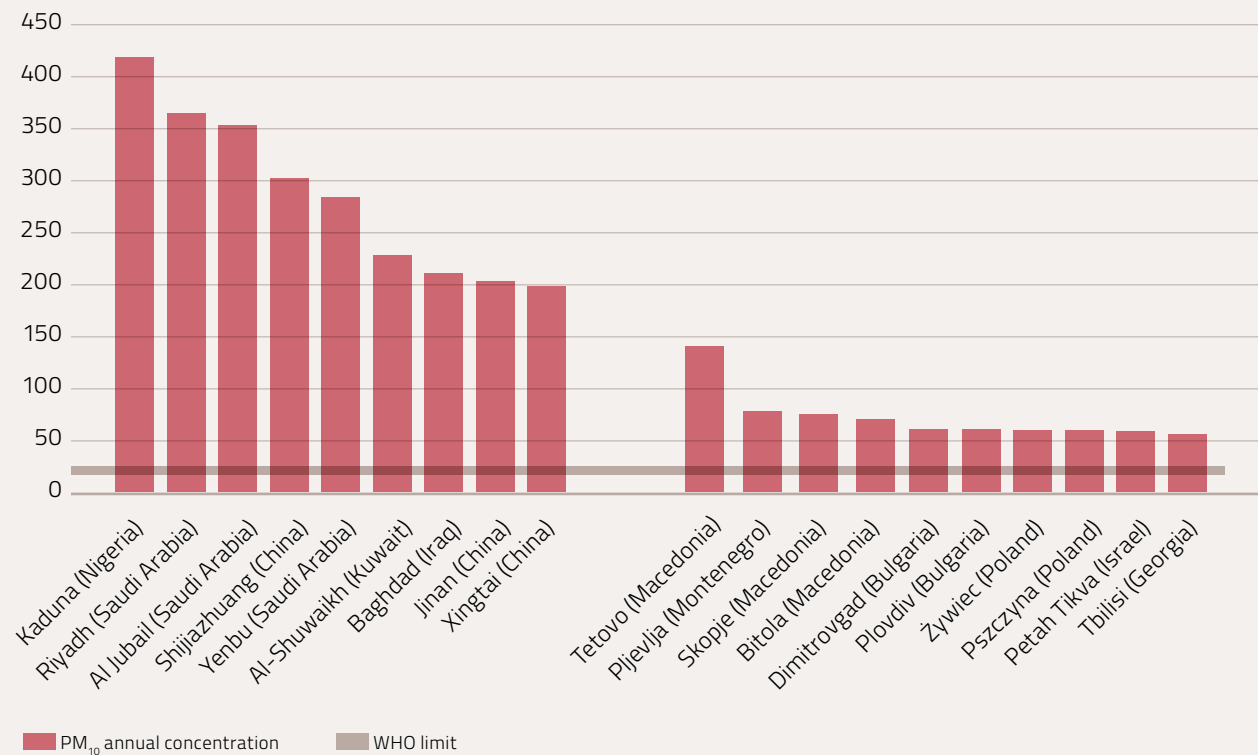
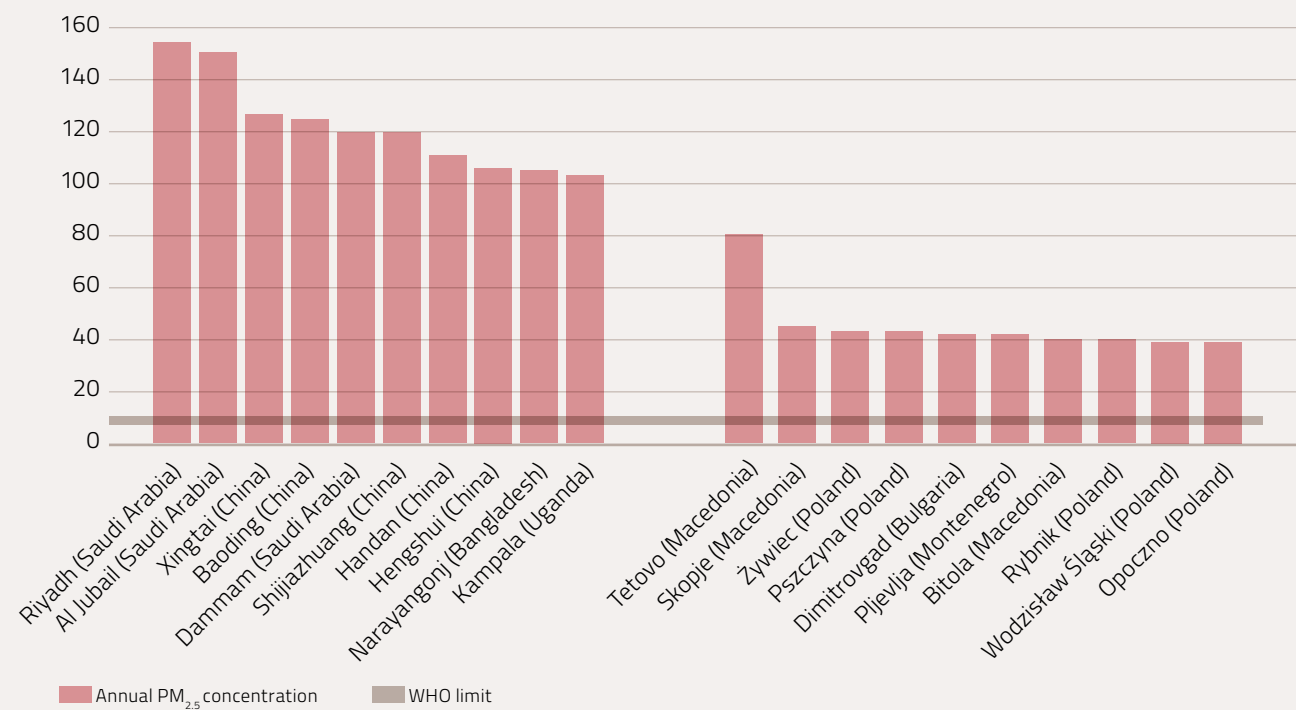
Figure 7. **Global map of modelled annual median concentration of PM<sub>2.5</sub> level**<sup>29</sup>



Figures 8 and 9 present the top 10 countries globally and in Europe based on the average annual concentrations of PM<sub>2.5</sub> and PM<sub>10</sub>. We can see that in many places globally the concentration of particulate matter can be more than tenfold higher than the WHO guideline annual mean value.



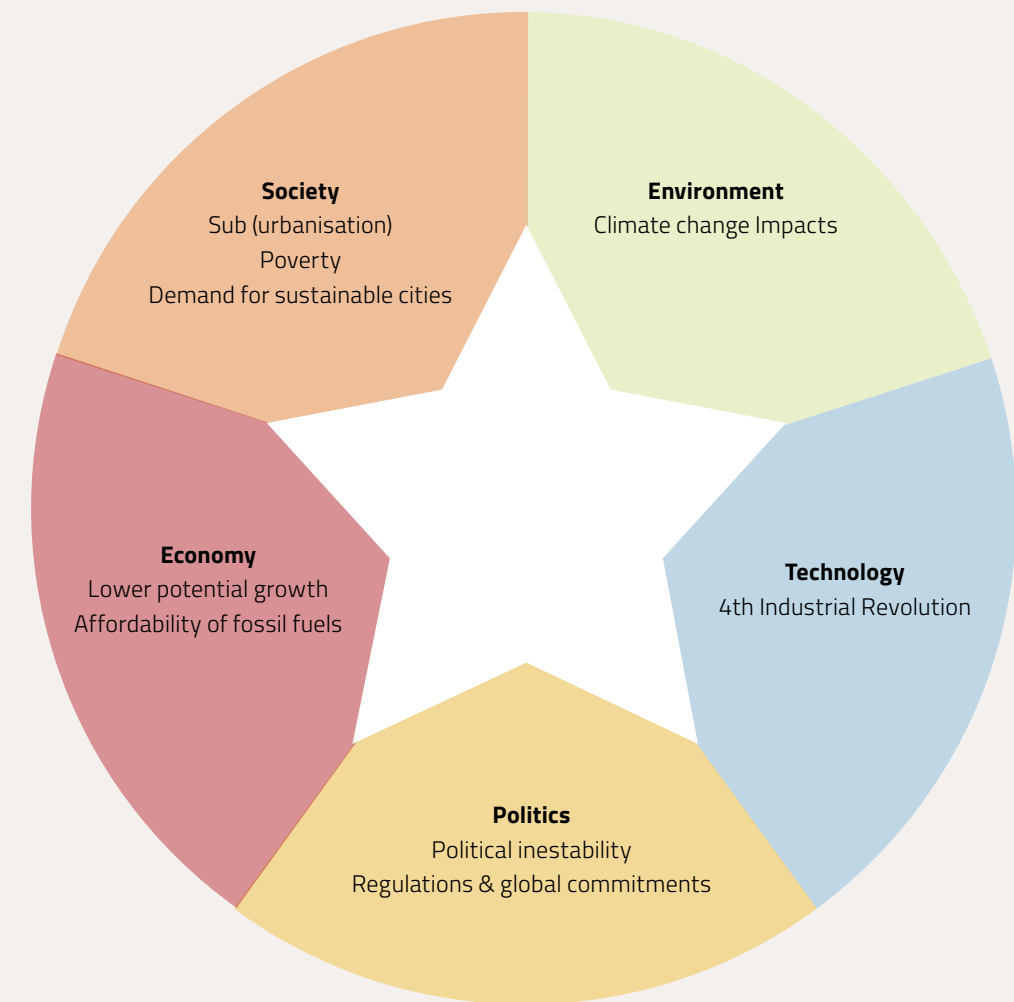


Figure 8. Top ten most polluted cities globally and in Europe – PM<sub>10</sub>, 2013-2015 [ $\mu\text{g}/\text{m}^3$ ]<sup>30</sup>Figure 9. Top ten most polluted cities globally and in Europe – PM<sub>2.5</sub>, 2013-2015 [ $\mu\text{g}/\text{m}^3$ ]<sup>31</sup>

## Global trends & the worldwide market for clean air solutions and technologies

Several trends were identified as having the greatest impacts on city development, both on a global level, and with these trends being reflected more specifically in the European context. As a result, they will logically affect the global demand for clean air solutions:

### Worldwide market for clean air solutions and technologies

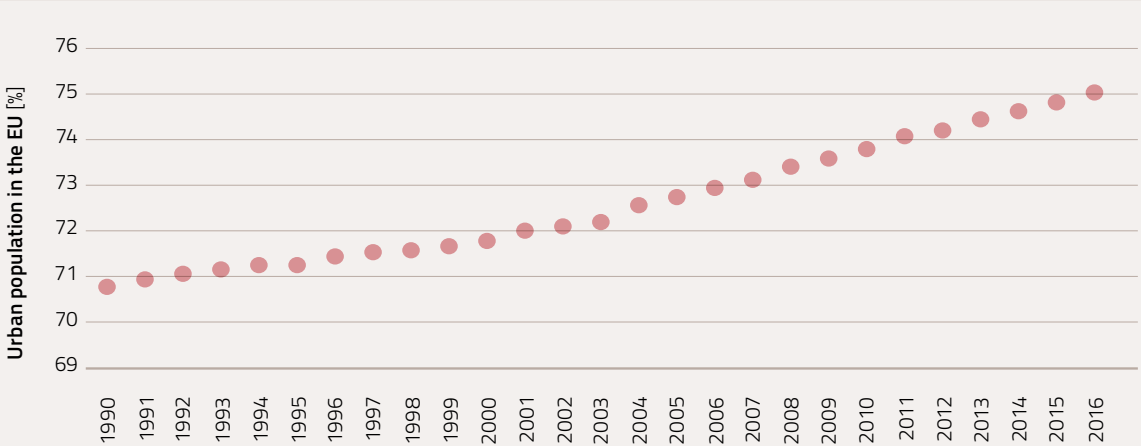


Source: Deloitte's own elaboration

### (Sub)urbanisation

The most prevalent trend affecting cities globally is an increasing level of urbanization. Today, cities are home to more than 50% of the world's population, generate more than 80% of the world's GDP, and consume 75% of the world's natural resources. On top of this, the UN estimates that our global population will rise to 9.8 billion by 2050, with the majority of this growth occurring in cities, meaning that an estimated 66% of the global population will be living in urban areas by 2050.<sup>32 33 34</sup> Needless to say, this will result in increasing pressures on cities socially, economically, infrastructurally, and environmentally.

Figure 10. **Urban population in the European Union, 1990-2016** (% of total population)<sup>35</sup>



Urbanisation will be one of the defining factors in shaping the future of city landscapes in Asia and Africa. However, due to low fertility rates, the population of Europe is actually predicted to fall by around 12% by 2050. This being said, the Old Continent is also dealing with a related trend, mainly **dispersive urban growth**. The EEA reports that, over the past 50 years, European cities expanded on average by 78%, whereas the population has grown by only 33%.<sup>36</sup> As a result, we may surmise that the space consumed on a per inhabitant basis has just about doubled over that period. As the trend has intensified in recent decades, and it is predicted that this phenomenon will continue into the future.

**This growth of low density and mono-functional urban areas increases cities' reliance on cars, and reduces the viability of centralised heating systems.** Taking into consideration the way in which urban service systems are currently developed and deployed, we may easily see how the phenomenon of suburbanization solidifies a negative trend with regard to cities' air quality.

Poverty

**There is no question that the world is moving toward the eradication of extreme poverty.** The number of people living in extreme poverty globally fell significantly between 1999 and 2013, from 1.7 billion to 767 million.<sup>37</sup> However, the scale and depth of relative poverty, by virtue of definition, is vastly underestimated in this figure, and the number of people who cannot afford an adequate standard of living vis-à-vis other, more developed societies, is much larger. Considering the rates of projected population growth, and taking it into account along with the predicted rates of urbanisation, a greater affordability of clean energy solutions is becoming an increasingly pressing need.

**In particular, poverty is a serious issue in Europe.** According to Eurostat, 24% of people in the EU-28 were at risk of poverty or social exclusion in 2014.<sup>38</sup> Practically, this means that a full quarter of the population cannot afford unexpected expenses, adequate heating of a dwelling or durable goods such as a car, or struggle to pay their monthly bills.

The issue of poverty is a serious challenge for the adoption of clean heating and transport solutions. Simply put, many inhabitants of cities cannot afford to buy cleaner cars, or use less polluting heating fuels. As a result, more affordable solutions are necessary, and by necessity, there is an increased pressure on the public sector to bear the costs of clean heat and transport.

Societal demand for clean air

**Air pollution is more and more often reaching the front pages of newspapers, representing not only a growing consciousness, but also discontent on the part of inhabitants demanding clean air.**

It is worth noting that it is primarily the growing global middle class who have both the influence and means to voice their dissatisfaction with urban air quality. A few years back, pollution became the number one cause of social unrest in China, and similarly, it is now causing an exodus of the middle class from India.<sup>39</sup>

Interestingly, a recent study tried to estimate the willingness of citizens to pay for smog in China. The study shows that the willingness to pay for smog mitigation accounts for about 1% of income (1590 RMB annually ~ €213, and is closely related to household income, energy costs, and "not in my back yard" attitude.<sup>40</sup> Moreover, it demonstrated that awareness of smog, and an understanding of the risks serve to increase the acceptance of the public to take on additional charges relating to air quality. In fact, another study found a strong correlation between awareness and acceptance of the implementation of a congestion charge policy in China.<sup>41</sup> The study, conducted in Hangzhou, revealed that 46.26% of respondents were willing to pay a congestion fee during peak hours, and the average amount people were willing to pay was €3,85 per month.

**In general, the societal expectation for clean air, and demand for sustainable solutions is increasing.** Nielsen's 2015 Global Corporate Sustainability Report indicated that globally, 66% of consumers are willing to spend more on a product if it comes from a sustainable brand. Millennials displayed an even more substantial commitment, with 73% of surveyed millennials indicating a similar preference. Additionally, 81% of millennials go so far as to expect their favourite companies to make public declarations of their corporate citizenship.<sup>42</sup>

The increasing demand for clean air and awareness can be observed in property prices and in the growing sales of products which mitigate the effects of smog. Recently, during this year's Diwali, New Delhi breached a critical limit, with particulate levels 30 times above the WHO's safe limits and thick grey smog hanging over the city. As a result, the demand for the most popular air purifiers sky-rocketed over the course of a few days.<sup>43</sup> This trend can also be observed in property prices in Delhi, which have fallen 21.7% between 2014 and 2016 according to the MagicBricks property index – a phenomenon which can hardly explained by other reason than the choking smog.

Climate change impacts

**Climate change complicates efforts to tackle smog and air pollution as it exacerbates their effect.** The latest IPCC assessment identifies a range of climate change impacts that are already being felt in many urban areas. These include a rise in sea levels, accompanying coastal flooding, inland flooding and hydrological hazards. A full 70% of cities globally are already dealing with the effects of climate change, and nearly all are at risk. With over 90% of all urban areas being located on coasts, most cities on the Earth are at risk of flooding from changes in sea levels, and powerful storms.

European cities are more frequently experiencing the negative effects of climate change, which are expected to increase in frequency and intensity. Manifestations of these phenomena include extreme events such as heatwaves, flooding, water scarcity and droughts.<sup>44</sup>

There is an increasing body of research showing that climate change may increase the likelihood of, and intensify the effects of smog, e.g. by increasing its resilience through more stagnant air conditions.<sup>45</sup> As urban climate change-related risks are likely to increase they will continue to deepen the effect that smog has on cities across the globe.

Regulations and global commitments

Since the **Gothenburg Protocol** helped reduce industrial air pollution and then widespread acid rains, the efforts of the international community have turned to the problem of smog and air pollution in cities.

Both national and international regulators are looking to establish more stringent emission standards for vehicles and reliable emission testing, with similar trends presenting themselves in regards to household furnaces and fuels. Besides concerted national policy action, cities (notably the C40 Alliance which is a strategic partnership of large cities from across the globe), are trying to reduce the problem of smog themselves through cooperation and coordinated municipal policies.

Additionally, the **Paris Agreement**, as well as complimentary national policies are designed to limit greenhouse gases, thus serving to promote solutions which have compound benefits in improving local air quality. Similarly, the recent, international alliance led by the UK and Canada to phase out the use of coal in energy production sets a positive precedent by both reducing carbon emissions, as well as the release of particulate. By supporting the advancement of clean technologies, such alliances can not only help achieve global climate objectives, but also help tackle air pollution on a more local level.

As with global warming, **the European Union** shows a strong commitment to clean air, setting targets beyond those agreed in the Gothenburg Protocol. There has, however been some degree of erosion to these regulations, largely as a product of the recent tide of populist political movements, which tend to seek immediate to near term benefits. This has manifested itself particularly in the field of vehicle emissions, where efforts to ease standards by giving additional lead time and more lenient NO<sub>x</sub> limits to automakers has had a noticeable effect.

### Lower potential growth

In 2015, an IMF study suggested that countries may have to adjust to a new reality of lower potential growth.<sup>46</sup> In advanced economies, this decline reflects the continuing impact of aging populations, as well as lower capital and productivity growth. Fortunately, two years on, the short-term outlook is more promising. The World Bank in its Global Economic Prospects forecasts global economic growth to reach 3.1% in 2018, after a much stronger than expected 2017. Amid increased domestic demand and investment, the GDP growth in Europe has gained speed. However, concerns and uncertainty over the longer term remain, with higher public debts, weak productivity growth, and spreading protectionism all lingering as potential pitfalls.<sup>47</sup> As potential investors in technology development are concerned with the long-term economic outlook, these factors can discourage investment.

### Affordability of fossil fuels

Fossil fuels are far from being depleted. In looking at oil and natural gas reserve-to-consumption levels from 1980–2014, we can see that the world has at least 50 years of reserves in the ground. For coal, there are even more potential reserves at current consumption rates than there are for both oil and natural gas.<sup>48</sup>

**Yet, despite technological advancements, the affordability and quality of fossil fuels is generally decreasing.** In many places, such as Russia or Canada, we have seen the emergence of problems relating to extraction, largely due to the exploitation of more peripheral or lower quality deposits. As a result, governments and private investors, especially in the affected regions, are incentivised to invest in technologies that are cleaner and more efficient. This trend is evident for alternative renewable energy sources such as wind and solar power generation which are both becoming price competitive with conventional sources.

### The 4th Industrial Revolution

The Fourth Industrial Revolution is the term used to describe the ongoing technological changes that are disrupting the economy and society. **This umbrella includes three types of technologies, namely physical, digital and biological, all of which are creating unprecedented opportunities for innovation and scientific breakthrough.**

Like the industrial revolutions which preceded it, the Fourth Industrial Revolution has the potential to increase global income levels and improve the livelihoods of populations around the world. In terms of tackling smog, the innovation and breakthroughs happening in fields such as sensors, big data, artificial intelligence, automation or energy storage, among others, could completely reinvent the fields of heating and transport. Additionally, many innovations blur the lines between the physical, digital and biological realms, creating opportunities particularly for tackling smog, for which all of these areas are components.



## Current situation and policy in the EU (including state-of-play and outlook for the European legislation in the field of air pollution)

### The EU's fight with air pollution started more than 40 years ago<sup>49</sup>

On the transnational level, the effort to combat air pollution started in earnest with the **Convention on Long-Range Transboundary Air Pollution**, which was signed in 1979 by a number of countries in the Northern Hemisphere. The Convention came about following a greater awareness of the impacts and causes of acid rains in the 1960s and 70s, and aimed to gradually reduce (and eventually) prevent air pollution. Several new EU countries played a leading role in driving this initiative.

There were several protocols which further specified the commitment to cut emissions of air pollutants. Notably, the so-called **“Gothenburg Protocol”** in 1999 was a single international agreement dealing with multiple pollutants and with multiple effects, and was later transposed into commitments enshrined in EU law. Additionally, it is worth noting that scientific research and tools heavily influenced policies in the EU.

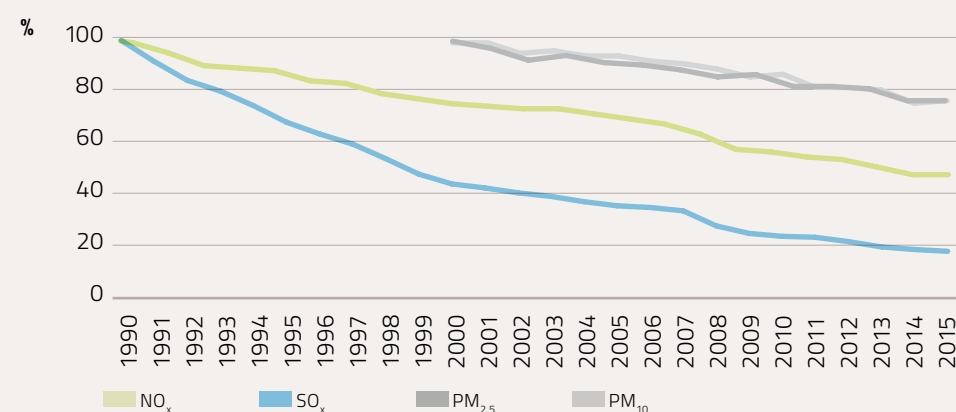
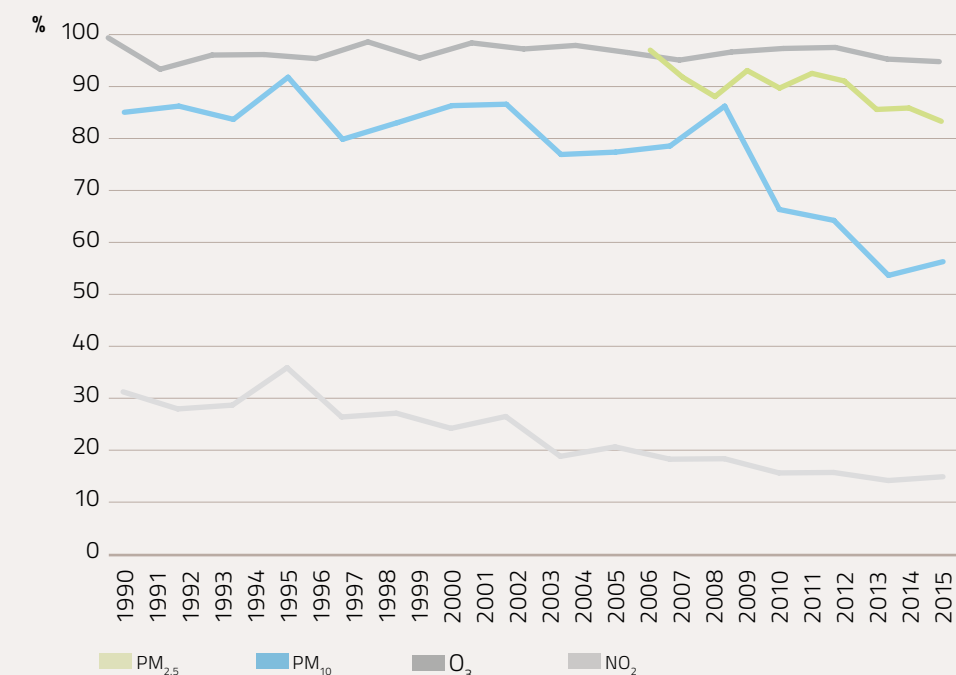
### Emissions of air pollutants dropped significantly, but remain high<sup>50</sup>

Since these commitments, the EU countries have made significant progress in limiting the emission of air pollution. SO<sub>x</sub> were the pollutants which saw the greatest levels of reduction across the 28 countries of the EU (levels currently sit 89% lower than in 1990). This is a result of a combination of measures introduced in energy-related sectors, most importantly from fuel switching to low-sulphur variants (such as natural gas), and the introduction of techniques to remove SO<sub>2</sub> from exhaust gases.

Emissions of the other main air pollutants have also dropped considerably since 1990, including the three air pollutants primarily responsible for the formation of ground-level O<sub>3</sub>: CO (-68 %), Non-Methane Volatile Organic Compounds, or NMVOCs (-61%) and NO<sub>x</sub> (-56%). Road transport is the primary contributor to this reduction, through regulation of exhaust emissions, while the energy sector introduced low-NO<sub>x</sub> burners and techniques to remove NO<sub>x</sub> from output. However, the pace of reduction has slowed down in the past decade.

This slower pace can also be observed in the urban exposure to bad quality air (Figure 12). Except for the exposure to NO<sub>2</sub>, particulates and ozone remain unacceptably high.



Figure 11. EU-28 emission trends for key air pollutants<sup>51</sup>Figure 12. Percentage of EU urban population exposed to air pollutant concentrations above WHO air quality guidelines<sup>52</sup>

## There are many lessons to learn from climate change action

**Amid rapid achievements in the 1990s, a more substantial challenge – climate change – and has since grasped the attention of international environmental action.** To put this shift into perspective, the Grantham Research Institute estimated that there are approximately 1,400 climate change relevant laws worldwide, up from around 70 in 1997.<sup>53</sup> Although comparable figures are not readily available for air pollution policies, an informed estimation of the number is that it is certainly at least 10 times lower. This is a clear indication that climate change issues attract a lot of political attention, and as such, resources. To speak to this, access to clean air was not explicitly included under any of the Sustainable Development Goals.

## Agenda 2030: Sustainable Development Goals to transform our world

Among the 17 Sustainable Development Goals proposed by the United Nations there are 6 related to environment or natural resources.

**SDG 6:** Clear water and sanitation: clear accessible water for all, no more deaths caused by diseases associated with insufficient water supply, poor hygiene and sanitation.

**SDG 7:** Affordable and clean energy: increasing use of renewable sources, increasing efficiency and universal access.

**SDG 12:** Responsible consumption and production: promoting energy and resource efficiency, access to basic services and infrastructure, stakeholders' interaction, decent jobs and better quality of life for all.

**SDG 13:** Climate action: fighting climate change and minimizing its impacts applying affordable solutions to engage in the

process even the poorest countries.

**SDG 14:** Life below water: carefully managing of water resources is crucial for sustainable future.

**SDG 15:** Life on land: stopping reserve land degradation, biodiversity loss and fighting desertification.

Although the air pollution is not explicitly mentioned in either one of the Sustainable Development Goals, it is undeniably supported by SDG 6, 7, 11 and 12. Also development of infrastructure and innovative activities (SDG 9) and making cities more sustainable (SDG 11) might reduce emission from transport and heating. However, more explicit inclusion of air quality issue in the Agenda 2030 – in a form of separate SDG – could plausibly raise social awareness and stimulate governments to strengthen their efforts in tackling smog.



**The fact that there is so much effort applied to limiting global warming is very positive.**

Even though climate change-related policies are directed specifically at limiting emissions of greenhouse gases, and of carbon dioxide in particular, harmful air pollution is actually a by-product of the very emissions being combatted in relation to climate change. As a result of the involvement of sectors and solutions which are relevant to tackling both climate change and air quality concerns, every action taken to advance the cause of global warming can also help limit urban air pollution. Initiatives to improve energy efficiency, increase the use of renewable energy or implement clean transport solutions, are clearly benefiting both agendas.

**This being said, the two issues differ in terms of the significance that they associate with each distinct source of emissions.** For example, a large coal fired plant located in the countryside is higher on the contributor list to climate change than that of air pollution in a given country. On the other hand, antiquated coal-fired furnaces in a city can be the central cause of harmful air pollution, while having a minor overall effect on global warming. As a result, there is a whole spectrum of issues which have limited impact on climate change, but are main contributors to smog, and thus require both a distinct agenda, and a specific constellation of solutions. In a way, it must be said that having the spotlight set on an interconnected, but distinct issue makes tackling smog more difficult.

This is not to say that air pollution regulation cannot benefit from the efforts being applied to the problem of climate change. In particular, with all of the developments in the field of addressing global warming, there are a multitude of lessons to be learnt from the experience of first raising, and then acting on an international environmental issue. Specifically, the issues of how to regulate and control emissions, as well as effectively involve stakeholders are areas in which solutions can be taken directly from the climate change playbook.

Heating and Cooling Strategy – sustainability energy policy

Half of the EU’s energy produced is consumed by heating or cooling the households and industry buildings.<sup>54</sup> Just 16% of this energy is generated from renewable sources, while 84% of heating and cooling is still heavily depend on fossil fuels.<sup>55</sup> Over three quarters energy produced is engrossing by heating EU households and hot water – 79% of total final energy use. 3% energy is using for cooling and it consumption increases during the summer months. Reduce energy consumed can be saved by upgrading heating and cooling appliances. Advanced construction

and high-performance insulation materials would allow increase energy efficiency. Therefore, at the beginning 2016 European Commission proposed Heating and Cooling Strategy. EU energy proposal focuses on stopping the energy leakage from buildings, expanding the efficiency and sustainability of heating and cooling systems, supporting efficiency in industry and reaping the benefits of integrating heating and cooling into the electricity system.<sup>56</sup>

Clean Air for Europe CAFE (CAFE) – environment policy

It is now well understood that air pollution has a negative impact on both individual health and the environment, a distinct shift from the attitudes expressed at the beginning of the 21<sup>st</sup> century. As a result of scientific research<sup>57</sup> on the adverse effects of air pollution, the European Commission began drafting unified policies related to tackling pollution caused by particulate matter and ozone. This has since become a major focus of the Community’s air quality policy.<sup>58</sup> In 2008, as a result of strengthening links between research and policy, the European Commission passed the Clean Air for Europe (CAFE) Programme - the long-term strategy regarding air pollution control in Europe. The aims of CAFE are the transparent assessment of the air quality of each member state on the basis of common methods and criteria, the facilitation of providing information to the public, and the promotion of cooperation between EU members in reducing air pollution. CAFE, along with the National Emission Ceilings (NEC) Directive NEC and Ambient Air Quality (AAQ) Directive , is

a main component of the EU Clean Air Package designed to deliver perceptible benefits across the EU by 2030.<sup>59</sup> CAFE itself focuses on measuring contaminants, while developing supporting research and propelling innovation within the context of increased European cooperation on the matter of air pollution. For their parts, the NEC and AAQ refer to air quality policy frameworks which specify limits on concentrations of certain pollutants on both the municipal and national levels. It is also worth noting that CAFE focuses on a specific group of air pollutants – namely PM<sub>10</sub> and PM<sub>2.5</sub>, sulfur dioxide, nitrogen dioxide, benzene, carbon monoxide and lead. The entity responsible for collecting information on emissions (and communicating it) is the European Environment Agency. Once the findings of the EEA are articulated, CAFE allows the European Commission to take enforcement action against any member country which does not comply with the existing laws. So far, infringement actions for PM10 excesses have been filed against 16 countries.<sup>60</sup>

EU regulatory environment for clean air

There are several existing policy instruments to improve air quality

In general, the EU has a two-pronged approach to tackling air pollution. On one hand, the EU regulates the problem itself - the concentration of air pollution in cities – and this is achieved through the **Ambient Air Quality (AAQ) Directive**. On the other hand, through various other policy instruments, it intends to regulate the source of the problem – the emission of air pollutants – most notably through the **National Emission Ceilings (NEC) Directive**, which regulates the level of aggregate emissions produced by each member state. Logically, the intention of the latter instruments is to help achieve the former.

Apart from pollution limits set for the member states, **the EU has also introduced restrictions on the exhaust emissions for new vehicles sold in the region**. Following the recent car emission scandal which showed that the reported values were not reflected under real driving conditions, the EU has introduced new laws which oblige car makers to test the cars that they want to introduce in the EU under real world conditions and not in laboratories. Further compounding the problem, as countries use the published technical info of motorized transport so as to determine national vehicle emissions, this scandal must have resulted in the underestimation of reported emissions.

But the outlook also doesn’t look promising as efforts are not ambitious...

The NEC Directive sets emission levels for 2020 and 2030, which are directly copied from the renewed Gothenburg Protocol. An analysis performed by the IIASA shows that these requirements bring **little additional reductions** beyond what’s expected to come out of other legislations, such as renewable energy directives.

The greatest effort beyond implementing existing legislation will be that applied to achieving the PM<sub>2.5</sub> targets (additional reduction of 17% from 2005 levels). This in turn shows a limited commitment to tackling the problem, and means that **the NEC directive is not going to be the primary driver of emission reductions**. This result confirms the secondary importance of the air pollution issue among environmental concerns, and that the achieved improvements will be primarily derived benefits from other environmental agendas.

Member state lobbying can be seen as the key reason for reduced ambition, with **over 50% of originally proposed limits for 2030 weakened during negotiations**. Apart from weak targets, there is a lot of space for countries to comply with the regulation without actually meeting the targets. For example, if a particular limit is breached, countries can average the results with consecutive years in the case of an exceptionally cold winter

or hot summer. They also have an option to remove emissions from their inventories, or even swap pollutants, or both if certain conditions are met.

These timing related provisions are economically viable for greenhouse gases, where the year-on-year inventory is the concern. But for air pollution they come at the cost of urban populations. However, air pollution issue is gaining importance among environmental concerns, even though the achieved improvements will be primarily derived co-benefits from other environmental agendas, particularly climate policy.

**Noteworthy is that the BaP is not included under any of the directives**. The AAQ Directive sets target values for BaP, but they are not binding in practice. As BaP is a serious problem, affecting the livelihoods of people living in cities with antiquated household heating systems (especially in Poland and Bulgaria), and it remains a serious limitation to the efficiency of the EU policies as a result.

And more coordination is needed

Coordination across all environmental policies is needed to achieve tangible results on all fronts. It is important to identify the co-benefits and trade-offs in combating air pollution and other environmental issues, such as climate change, biodiversity loss, as well as to address them effectively with specific policy instruments.

Although air pollutants and greenhouse gases often come from the same sources, international agreements generally treat them separately. Similarly, in Europe, the policy action to tackle smog and air pollution is bundled under the 2013 **Clean Air for Europe Programme** (CAFE), while there are separate programmes to deal with climate change and emissions of greenhouse gases.

**Even though the EU is a global leader in promoting and executing “green policies”, larger coordination of international efforts is needed**. Air pollutants can travel over long distances – especially ozone and particulate matter. They have an international impact, and need to be managed similarly to climate change. Collaboration has to occur on the regional, national and international levels to enable the successful implementation and upholding of policies relating to pollution control.

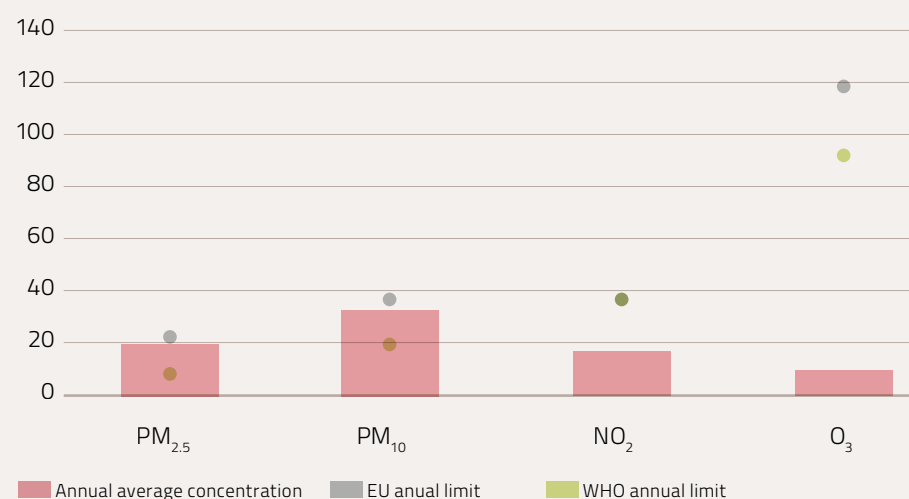


## Current situation and outlook in selected EU countries



### Bulgaria

Figure 13. Concentration of air pollutants in Bulgaria<sup>63</sup>



Ranking fourth highest globally in terms of mortality rates attributed to air pollution, there is little doubt that air quality is a serious problem in Bulgaria.

More tangibly, the IEA estimates that 175 people per 100,000 inhabitants in Bulgaria die annually due to exposure to airborne pollutants. In terms of the greatest threats, Bulgaria has one of the highest urban concentrations of PM<sub>10</sub>, with annual mean concentration of almost 100% higher than the WHO limit (Figure 13).

PM<sub>10</sub> has a seasonal tendency, with an increased concentration appearing during the heating seasons in the autumn and winter. For this reason, more meaningful are daily values in relation to the number of days the limit was breached. In the EU, this maximum level of PM<sub>10</sub> is set such that a concentration above 50µg/m<sup>3</sup> can only be breached for a maximum of 35 days per annum (worth noting that the WHO sets the period of breach at maximum of 3 days). The intensity of the issue

becomes clear then when a full 75% of measuring stations in 2015 in Bulgaria were registering values above both the allowed concentration as well as period. It is calculated that **78% of the urban population in Bulgaria is exposed to PM<sub>10</sub> levels above EU standards.**

This comes as no surprise as PM<sub>10</sub> emission has continually increased in the country for the last 15 years, meaning an overall growth of 38% over the same period. As was previously explained, an important driver of PM<sub>10</sub> emissions is poverty due to its relation with poor sources of household heating, and as such, it should be of no surprise that among the 28 countries in the EU, Bulgarians are at the highest risk of poverty or social exclusion.

The situation is particularly acute in smaller towns, where citizens are burning wood, coal and any matter of waste as they simply cannot afford costly modern heat sources. This situation is directly related to the most harmful problems in Bulgaria – namely the emission of particulate – with 47% out of over 50 000 tonnes of PM<sub>10</sub>, and 81% of almost 29 000 tonnes of PM<sub>2.5</sub> being emitted as a result of heating.

On a national level, regulation is by and large limited to implementing EU directives, and even has proven difficult in terms of implementation. Bulgaria was the first member state to be ruled by the European Court of Justice to have failed to meet its ambient air quality obligations, in particular win limiting output of PM<sub>10</sub> from 2007 to 2014 in all urban areas. The court also ruled that Bulgaria failed to meet even the basic requirements on air quality plans to reduce PM<sub>10</sub> over the same period.

This uninspiring outlook is also confirmed by a well-regarded proxy of a “green economy” concept – namely the **Eco-Innovation Scorecard (Eco-IS)**. The Eco-IS captures different aspects of innovation, such as inputs, activities, resource efficiency, and socio-economic outcomes. Since 2013, Bulgaria continues to rank last by means of this evaluation, and remains merely a “modest innovator” by the same measure.

The Eurobarometer survey showed that 59% of Bulgarians think that the air quality has deteriorated in their country, and a similar share named air pollution as the number one environmental issue in the country. Even though the issue persists, awareness of the problem is quite high, and there have emerged several initiatives in the country to provide access to information and share recommendations on how to deal with the problem (see the text box).

### “Smog” App

Increasing access to information and awareness of smog is one of key issues in Bulgaria. “Smog” is an online calculator which translates the values of air pollution indicators that are measured by the facilities of the municipality scattered around the city. In brief, what this application serves to do is simplify the statistics, which would not otherwise be understandable to citizens. It was developed by an environmental NGO on a voluntary basis, and it even contains advice for people on how to reduce harmful emissions.

### Luftdaten Map

This is a voluntary initiative where city inhabitants can contribute to pollution tracking by sending information from their own sensors to the website.

Sources:

<http://smog.zazemiata.org/>

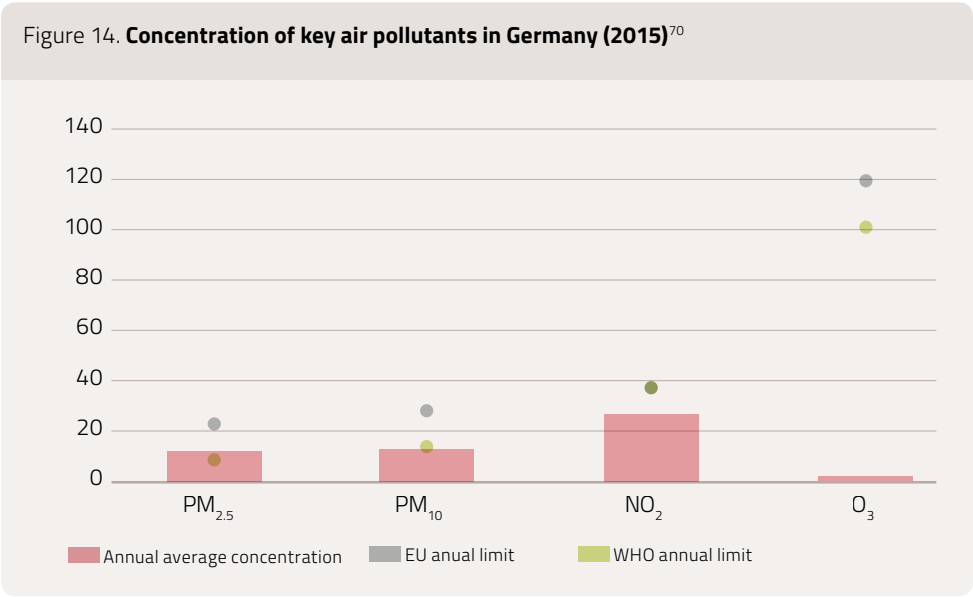
<http://sofia.maps.luftdaten.info/#13/42.6951/23.3326>

It must be noted that the above initiatives, although noteworthy in and of themselves, have come out of an impressive public discussion which promises to make change swift once resources can be allocated to tackling air quality. This view is strengthened by such community-municipal government collaboration such as that seen at the recent SOFAIR European Conference on Air Quality. During this event hosted in October 2017, high ranking municipal stakeholders considered innovative, often grass roots solutions which were previously pitched at a Climate-KIC supported event. In light of such dialogue, the situation can be understood as being very poor at the moment, but with a great promise for future change.



Germany

On a whole, Germany tends to fall in the European average in terms of air quality, achieving mean annual concentrations well within the EU standards. In fact, emissions of particulates have been gradually decreasing year-on-year with PM<sub>2.5</sub> and PM<sub>10</sub> having dropped by 38% and 24% respectively since 2000. This being said, it must be noted that even though the PM<sub>10</sub> average annual concentration across all measuring stations fell within both the WHO and EU standards (Figure 14), the daily limit was exceeded by 1 in 7 stations.



**The biggest air quality problem in Germany is nitrogen dioxide.** Even though Germany reduced its NO<sub>x</sub> emissions by close to 60% between 1990 and 2015, it remains the largest emitter of these gases within the EU (representing a 15% share of total NO<sub>x</sub> emissions).<sup>71</sup> Once again, although the annual mean NO<sub>2</sub> concentration across all stations was below the EU and WHO limits (Figure 14), the limits were exceeded in **57% of all the measuring stations placed close to traffic.**

Transport is responsible for 39% of total NO<sub>x</sub> emission in Germany, not surprising, as it is the nation with the highest number of passenger cars in the EU. It must also be noted that among the over 45 million motor vehicles currently in use in Germany, every third is between 10 and 20 years old, representing in excess of 15 million aged vehicles.<sup>72</sup> Also worthy of mention is the fact that the contribution of road transport to ambient NO<sub>2</sub> concentrations is considerably higher than other sectors, especially in urban areas. This is because the emissions are released particularly close to the ground, and by their nature, tend to be distributed over densely populated areas.

Considering the importance of car manufacturing in Germany, it is very tough for politicians, especially at the federal level, to introduce strict measures such as banning cars in cities. Nearly 6 million vehicles are produced each year in the country, generating a turnover of over €400 billion (2015) – a full 20% of total German industrial revenue.<sup>73</sup> As such, the automotive industry is also one of the largest employers in the country, a reality which potentially means that livelihoods exist at odds with air-quality policy. It is exactly this type of leverage which led to the suppression of proposed federal legislation to impose strict anti-smog legislation including “tougher speed limits and summer driving bans” back in 1995.<sup>74</sup> This type of pacification is the reason that smog-related legislation at the federal level has been left largely unchanged since the mid-1970s, instead looking to EU directives for guidance.

Following the diesel emissions scandal involving false NO<sub>2</sub> readings, environmental groups became even more persistent in pushing German federal government to tackle toxic smog. In what is interpreted as a way to protect the automotive industry, the chancellor avoided diesel car bans, instead deciding to commit more funds (€500m) to finding alternative means to tackle air pollution.<sup>75</sup> However, examples from various cities show that public initiatives to enforce EU limits can help introduce more stringent measures (see the text box).

Cars banned in the “car city”?

Stuttgart is often referred to as a “car city,” with carmakers Daimler and Porsche both headquartered there. Perhaps uncoincidentally, Stuttgart’s NO<sub>2</sub> levels are at least double the permissible levels. At first, the municipality depended on voluntary measures such as public appeals and reduced public transit fares, but they proved ineffective. Eventually, the government of Baden-Württemberg decided to introduce a ban on all non-conforming cars entering the city during periods of high pollution. It also installed a moss wall to filter particulate matter. As buses

constitute only 1% of vehicles in the city, but produce 20% of emissions, the mayor of Stuttgart is also looking to purchase electric buses. At the same time, following the diesel emission scandal, an environmental group DUH went to court to force the city of Stuttgart to ban diesel cars in the city. The court ruled in favour of the ban, and other German cities are expected to follow suit.

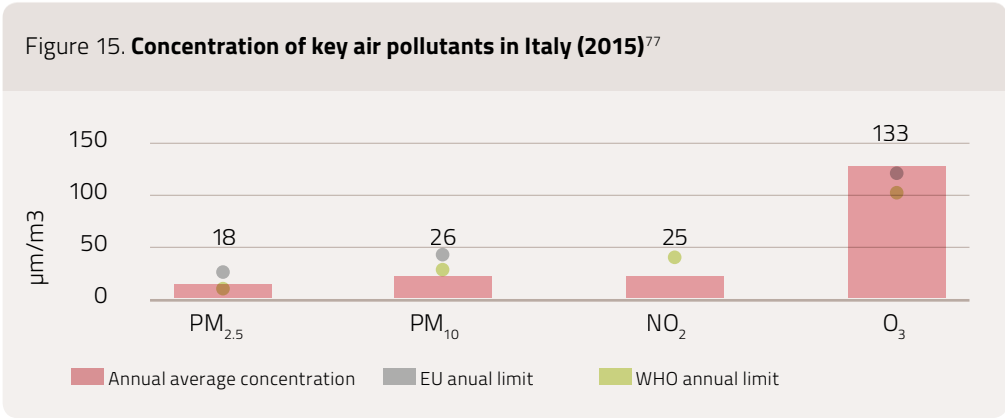
Source: <https://www.nytimes.com/2018/02/27/world/europe/diesel-driving-ban-germany-stuttgart.html>





Italy

Italy, and especially its highly industrialized Northern regions, are struggling with high concentrations of particulates and ozone – both being above the EU and WHO limits (Figure 15). The issue of air pollution has gained public awareness in Italy since the release of a highly publicized report by the EEA which quoted a figure of 84,000 premature deaths caused by air pollution<sup>76</sup>. **In fact, 76% of the urban population in Italy is exposed to ozone concentrations above EU standards, not to mention the 59% who face excessive levels of PM<sub>10</sub>.** Even though there have been steep declines over the last decade, emissions of PM<sub>10</sub> have actually increased by 8% between 2011 and 2015. Finally, despite the relatively low mean value of NO<sub>2</sub> concentration per annum, the value recorded in measuring stations located near traffic come close to the limit.



Much like Germany, Italy has one of the highest rates of motorization in Europe, but the issue of an aged vehicle pool is far worse, with a full 50% of passenger vehicles in Italy (ca 18.5 million units) being between 10 and 20 years of age.<sup>78</sup> Compounding the problem, Italy has a disproportionately high number of people who use cars to commute to work. In fact, only 40% of people in Rome and Naples travel to work using public transport<sup>79</sup> (the worst case is Palermo – 15% and Verona – 18%). In comparison, in Paris the rate is 80%, in Madrid – 63%, and in Warsaw – 60%.

As a result of these discouraging figures, one of the key elements of national policy is direct support for sustainable mobility. The Ministry of Environment has created a national programme called **“GREENINFINITY”** so as to encourage alternative urban mobility choices (rather than private automobiles). The basic premise is that municipalities set out plans, and then propose them to the Ministry for funding. For example, Florence will make use of nearly €2 million in national governmental funds to develop an integrated platform for mobility data sharing among users and city administrators.<sup>80</sup> This will allow for the creation of not only a community of users, but also enable municipal authorities to analyse users’ transport habits so as to improve systemic efficiency.

Pollution eating buildings

A prime example of a smog-reducing municipal initiative opened in 2015. This is the Palazzo Italia in Milan, which is one of the first buildings in the world to use pollution-eating cement. The building is composed of a photocatalytic cement that absorbs pollutants and turns them into harmless salts. Enrico Borgarello, the innovation director for Nemesis Studio (who designed the building) noted that “this is 9,000 square metres

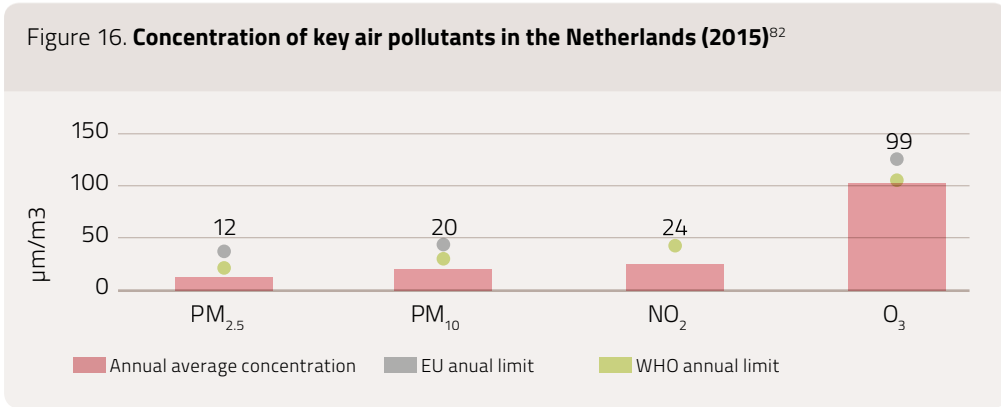
[sic] of active concrete and this can clean the air of the equivalent of exhaust gases from 100 diesel cars or almost 300 gasoline cars,” adding that “it’s a significant impact” for the city, which is committed to fighting air pollution in new and innovative ways.

Source: <http://www.dailymail.co.uk/sciencetech/article-3440356/The-buildings-suck-SMOG-Cement-absorbs-pollution-air-turns-harmless-salt-washes-rain.html>



The Netherlands

On the national level, air quality in the Netherlands is compliant with EU regulations. Only 2% of the urban population was exposed to NO<sub>2</sub> levels above EU standards, and no other pollutants exceeded guidelines.<sup>81</sup> However, as we have seen in previous cases, the results are aggregate figures, and thus do not necessarily constitute a full picture. In 20 of the 393 municipalities in the Netherlands, concentrations of particulate matter exceeded the upper acceptable limits, meaning that the Netherlands failed on a local level to comply with the EU particulate regulations.



This being said, the concentrations of coarse particulate matter (PM<sub>10</sub>) and nitrogen dioxide (NO<sub>2</sub>) decreased by nearly 20 percent between 2011 and 2015. On the other hand, according to the Dutch National Institute for Public Health and the Environment, NO<sub>2</sub> levels have increased since 2015, they are predicted to exceed suggested standards by 2020.<sup>83</sup> The main source of NO<sub>x</sub> and PM emissions is transport, contributing around 50 and 80% of the aforementioned contaminants respectively in the Netherlands.<sup>84</sup>

The government of the Netherlands has a comprehensive plan to address environmental challenges, including air pollution, with efforts centred around leading green growth. One of the primary instruments used by the Dutch government to promote environmentally friendly activities is a green tax, levied on indirect energy consumption of natural gas, electricity and vehicle fuels. In fact, the Netherlands has one of the highest green taxes in Europe. Recently, there has been a nationwide discussion on green tax reform, and the appropriate extent of taxation so as to balance the tension between revenue and environmental results.

In 2011, the government have launched the Sustainability Agenda, with ambitious goals of up to 20,000 electric cars on the roads and 85% of waste recycled by 2015. The unique feature of this

agenda is the very close involvement of the private sector, acknowledging their role in driving innovation towards green transition. For example, the Green Deals programme run between 2011 and 2015 identified over 185 private initiatives which could be accelerated and facilitated by the government.<sup>85</sup> One such example was the Green Deal signed by the Dutch government with Chemical companies Dow Benelux, Yara and ICL-IP Terneuzen in 2016.

This agreement enabled the three firms to trade manufacturing by-products with each other via an existing gas pipeline. As Dow produces waste hydrogen which is used in the others’ manufacturing process, the bilateral agreement enabled the latter firms to substantially reduce their respective manufacturing of hydrogen, and as a result, CO<sub>2</sub> emissions.<sup>86</sup>These initiatives flow through to the municipal level. For example, Amsterdam has launched its smart city programme, with multiple initiatives around smart urban development. Two themes – “Energy, Water & Waste” and “Mobility” have an important role in tackling air pollution in the city (see textbox). The city has set aside a budget of €34.4 million to invest in green solutions under the umbrella of renewable energy, circular energy and city resilience, which include air pollution.<sup>87</sup> As a result, the Netherlands has the highest number of electric passenger vehicles (115,223 in 2016) as well as public and semi-public charging points, including fast-chargers (27,265 in 2016) in the EU.<sup>88</sup>

Amsterdam Vehicle2Grid

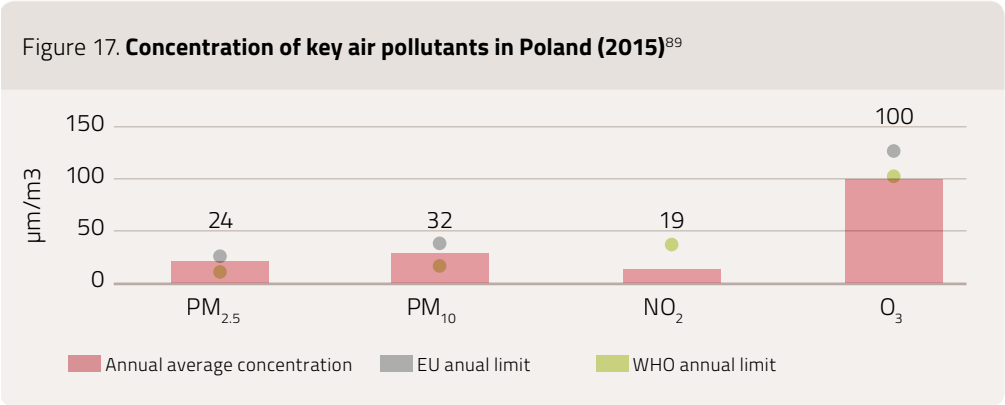
Vehicle2Grid technology is a technology which enables electric cars to be used as temporary batteries, either supplying power or absorbing a surplus as needed. Considering an average parking time of 14 hours, and a charge time of only 2 to 3 hours, there is a lot of capacity for temporary storage or supply. This technology is being tested by Alliander as part of a demo project in Amsterdam. There is also a pilot programme Boat2Grid. Source: <http://www.amsterdamvehicle2grid.nl/graphs/>





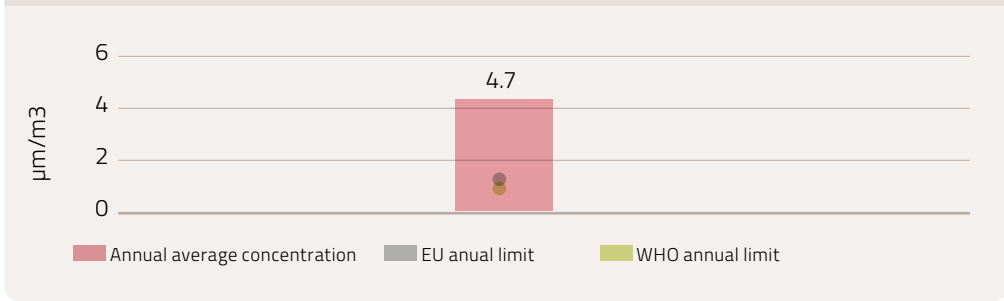
Poland

Next to Bulgaria, Poland is one of the EU countries with the most polluted air. Even though the average concentration of both types of particulate matter remains within the EU limit, **80% of the urban population of Poland is exposed to PM<sub>10</sub> concentrations above EU standards, and the concentration is the second highest after Bulgaria.** What is more is that the daily limit value was exceeded in **71%** of measuring stations. The issue remains pressing, even though the reported emissions of PM<sub>2.5</sub> and 10 have dropped over the last 15 years, the speed of this decrease has slowed between 2011 and 2015 (-10% and -11% respectively).



The most pressing issue in Poland is the concentration of benzo(a)pyrene (BaP), which is a carcinogen found in course particulate matter. In the EU, **99% of urban inhabitants are exposed to high BaP levels**, but Poland has an almost 22% share of the total EU-28 emissions of BaP – the highest out of all countries. In some towns in the south of the country, the limits are exceeded *as* much as tenfold. There is little mystery regarding the cause of these high readings, as the heating sector, and particularly the use of antiquated furnaces is responsible for 75% of benzo(a)pyrene emission on the EU level.<sup>90</sup> A direct consequence of this are approximately 45,000 premature deaths each year in Poland.

Figure 18. Concentration of benzo(a)pyrene in Poland (2015)<sup>91</sup>

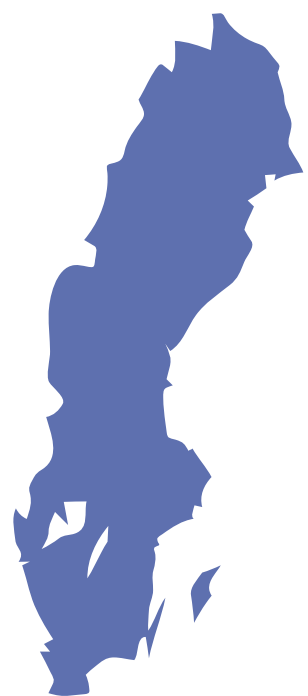


Generally speaking, home furnaces are responsible for a full half of air pollutant emission. Around 70% of single-family buildings – 3.8 million houses – are heated using coal burned in individual boilers and furnaces.<sup>92</sup> Of these, 80% are classified as ineffective and ‘high emission.’ Additionally, half of all coal-fired single-family houses are not equipped with a thermostat, and startlingly, 40% are not insulated. As a result, there is a great deal of upside potential with regards to air quality in Poland which can be accessed by simply increasing the energy efficiency and heating technology in single-family houses. It should be noted that up until now, owners of such dwellings received only limited support from public sources, contributing to the fact that as many as 76% of coal-fired boiler owners do not plan to replace these devices within the next two years.<sup>93</sup>

Another contributor to the smog problem in Poland is low rates of awareness among inhabitants. A survey by Krakowski Alarm Smogowy<sup>94</sup> showed that around 60% of people in Poland believe that the air they breathe is of good quality. Additionally, 65% of Polish people do not feel that they have access to sufficient information on air quality in their urban area, perhaps because in practice, municipalities in Poland do not provide information about air quality.

“I know what I breathe”

An example of the commercial sector engaging in attempts at smog reduction is to be found in Aviva – one of the biggest insurance companies in Poland. This firm is endeavoring to install 300 air cleanliness meters along with an accompanying mobile application throughout Poland. In addition, it created the “I know what I’m breathing” campaign – including TV spots, which will help to increase public awareness about the persistent smog issue.  
Source: <https://wiemczymoddycham.pl/>

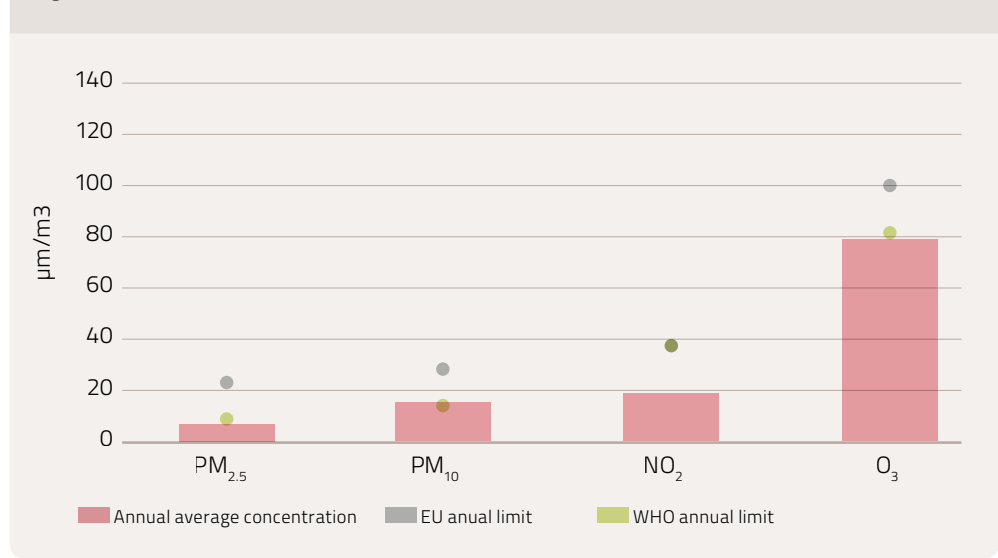


Sweden

Sweden has had a reputation for being an environmental pioneer since the 1960s, as it has actively initiated and engaged in several international collaborative projects to tackle environmental issues. For instance, it established one of the first environmental protection agencies (1967), hosted the first UN Conference on the Human Environment (1972), and co-initiated the Stockholm Convention (2001). This has led to high levels of public awareness surrounding environmental issues, and this in turn has manifested itself in widespread citizen engagement.

As a result, Sweden has the cleanest air of the countries here analysed, and it is the only country with all national concentrations within WHO limits in 2015 (Figure 19). Key pollutants are NO<sub>2</sub> and ground-level ozone originating mainly from transportation, which has decreased from 53% in 2004 to 41% in 2015 (as a percentage of total NO<sub>x</sub> emissions in Sweden). Despite these impressive results, key challenges in Sweden related to air pollution are to be found in the levels of course particles and nitrogen dioxide on the regional level.

Figure 19. Concentration of key air pollutants in Sweden (2015)<sup>95</sup>



On the municipal level, Stockholm has been identified as a green economy leader by LSE Cities. With a long track record of applying sustainable policies to energy, public transport and buildings, Stockholm received best in class results for almost all key drivers of a green economy within the LSE Cities' assessment framework. The study also shows that Stockholm is among the small group of cities which have been setting green priorities for over 40 years, a group which encompasses only 15% of the 90 cities in the sample.<sup>96</sup> There are several drivers of these results, including the building of a Metro system in response to predicted population growth, the rise of environmental awareness, as well as the oil crises of the 1970's.

It is worth noting that many of these policies were not considered as green goals at the time, but lead to such outcomes in the longer term. For example, in response to the 70's oil crises, Swedish cities invested heavily in expanding district heating networks, initially using conventional sources of fuel, but gradually changing over to renewable energy. This in turn resulted in multiple environmental benefits, among them improved air quality.

Prohibiting studded tires in parts of cities

Studded tires have been prohibited in some areas in the cities of Stockholm, Uppsala and Gothenburg, where levels of big particulate (PM<sub>10</sub>) have regularly been above the environmental quality standard. Much of this particulate was attributable to road surface wear dust, the release of which is severely aggravated by the erosion caused by studded tires. In all of the aforementioned cities, not only have the share of cars driving with studded tires has decreased, but the total traffic in the prohibition areas has declined. In Hornsgatan in Stockholm, traffic has decreased by about 15%, which corresponds to 4,000 fewer vehicles per day on a yearly basis. The particle levels are ~25% lower compared to before the prohibition, and the levels of NO<sub>2</sub> were also

positively affected (with reductions of ~9%). In Uppsala the total passenger traffic has decreased by 30-40% in Kungsgatan, which apart from reducing emissions, has had a positive effect on the efficiency of public transport. Overall, the number of cars with studded tires has decreased significantly, to about 20% of total cars in Kungsgatan. Programme in numbers: 20-25% reduction of emissions of particles from the roads of Stockholm. 30-40% reduction of passenger traffic in Uppsala.

Source: <https://sverigesradio.se/sida/artikel.aspx?programid=2054&artikel=4060922>



## Municipalities and cities as actors in fighting air pollution

The examples analysed in the previous section show that municipalities and cities have thus far been the driving forces of change. Both national and international policies have led to norms and standards that are important in setting a precedent for action. It might be said that these policies lay the groundwork for cascading into projects implemented on the ground.

There are many measures that can be introduced by municipalities that can have a significant impact on air quality in urban areas. Below we outline four main categories:

- 1 Restrictions on private motor vehicles** – many cities have introduced low emissions zones in their city centres, e.g. London, Amsterdam, and Stockholm. Some cities, for example Madrid, Milan or Paris, restrict access for cars to the city centre during periods of severe pollution. Such policies are very effective in controlling air pollution in both time and space, reducing the release of emissions in the most congested areas and busy times.
- 2 Improving low-emission public transport** – cities can improve their public transport fleet and introduce zero-emission buses. For instance, 26 cities in the C40 Alliance committed to collectively negotiate with bus manufacturers, and roll out more than 45,000 low emission buses by 2020.<sup>97</sup> In general, cities can also improve their public transportation networks to incentivise people to switch from commuting in cars. For example, only 19% of Europeans use public transport regularly. However, frequent public transport service (27%), better public transport coverage (26%) and cheaper tickets (25%) would encourage respondents who use cars or motorbikes to use public transport more often.<sup>98</sup>
- 3 Investment in low-emission heating systems** – creating a district heating grid like in many cities in Poland and Scandinavia can be very beneficial. This is especially true if residual heat from electricity production through cogeneration is used and it replaces inefficient residential boilers. Municipalities should also ensure high levels of efficiency in the heating system. Poland, which is a leader in terms of the extent of heating networks, still bears a colossal 88% rate of inefficient heating systems, with these accounting for 38% of heat delivered to end consumers.
- 4 Urban planning and management** – cities can leverage the most recent technological developments so as to introduce ways of improving transport capacity and efficiency without investing simply in new infrastructure. Measures might include investment in smart street lamps, real time traffic data, or smart parking programmes.

This being said, successes in countries such as the Netherlands and Sweden show that a strong commitment on the national level is required to achieve significant results on the municipal level. In particular, the provision of funds to invest in infrastructure and the implementation of cohesive policies (e.g. to introduce restrictions such as vehicle or fuel bans) are key.



### Cracow - Polish leader in the integrated policy against smog

The municipal and household sectors have the greatest impact on air quality in Cracow, that is individual coal fireplaces. They are responsible for about 50% of smog emissions. Emissions in transport account for almost 20% of the total, which also includes inflow, industrial and secondary emissions. The City of Cracow runs on a large-scale the Low Emission Reduction Programme (LERP), which aims to replace old coal furnaces with ecological heating sources. Within the framework of the LERP since 1995, about 37,000 have been liquidated. A very important supplement to the LERP is the Local Coverage Programme, which allows for the return of the difference in heating costs for the poorest inhabitants after replacing the heat source with ecological ones. On the basis of the resolution of the Regional Assembly of the Małopolska Region, from 1 September 2019, a total ban on the use of solid fuels (use of coal and wood for heating houses and flats) will be in force in Cracow. The city uses many solutions to reduce emissions in transport. These include bus lanes, limited traffic zone, increasing the paid parking zone and encouraging residents to use the public

transport. Cracow invests in a modern fleet of ecological vehicles that meet the EURO 5 and higher standards, as well as electric buses. A Wavelo city bike system is available and new bicycle paths are built every year. In addition, thanks to the 651 million euro from the EU Connecting Europe Facility (CEF) programme, on-going modernization and expansion of railway infrastructure in the city enables the development of an efficient agglomeration transport system.

Krakow also implements a long-term programme of planting dust-catch vegetation. In 2017, 2,944 trees were planted, 210,016 shrubs and creepers in road lanes, 10 ha of flower meadows were created. Only in the years 2016-2017, the area of green areas increased in Cracow by approx. 47 hectares. Recent data from the Voivodship Inspectorate for Environmental Protection show that over the last 5 years, PM<sub>10</sub> concentration has dropped by about 20%.

Paweł Ścigalski  
*Special plenipotentiary on Air Quality issues, Municipality of Cracow*

Besides the necessary support from the national and regional governments, collaboration between cities, and their representation in both negotiations and discussions on environmental issues should not be underestimated. In order to align agents in combatting pollution specifically, and more generally to advance the pace of bold climate action, the 40 largest cities in the World created the C40 Alliance. C40 mayors help advance a shared agenda through collaboration, knowledge sharing, and increased visibility of implemented climate action in cities. According to the C40, one third of the realized projects reported were directly influenced by collaboration between cities. What is more is that 70% of C40 cities have implemented new, better, or faster climate actions as a result of participating in C40 networks.



## Smog and air pollution – lessons learned so far (key research, policymaking assessment)

As we have seen, the issue of air quality is not a simple one. The sheer number of stakeholders, agents, and mechanisms (both political and economic) surrounding this problem mean that any solution will have to be multi-faceted. We have also seen that coordination between all levels of social organisation, from local communities to municipal, national, and supra-national entities is required to successfully implement and uphold policies relating to pollution control. Bearing this context in mind, it would be best to now have a look at some specific mechanisms which might be implemented to better coordinate the massive web which underpins positive action.



## Implications for innovators

Chapter 4 explored the current situation of air quality globally, and looked at global trends that affect the market of clean air solutions. Additionally, policy frameworks on both the national and municipal levels were examined. Both areas were explored with special attention paid to a context framed by the EU.

It is clear that the issue of air quality is gaining momentum, as the problem continues to intensify in urban areas worldwide, with multiple drivers deepening their effects moving forward. However, ongoing technological advancements create a fertile environment to develop solutions to tackle this problem.

Our analysis of selected EU countries shows that the landscape of current emission levels and policy solutions is complex. While availability of technologies is not a problem, it is clear that to create an environment which promotes the implementation of innovative solutions, commitment from national and municipal governments is required. For this reason, innovators should keep a close eye on the regulatory developments and be open to co-operate with the public sector.

## Lessons learned so far

**It all starts with public awareness. Public awareness of the problem and its urgency is crucial to accept the burden of policies such as congestion charges.** Awareness helps people see the overall societal benefits of such policies, and makes them more willing to accept the restriction that these policies impose.

In fact, there is extensive research showing that citizens are more likely to take action on climate change if the co-benefits are emphasized.<sup>99</sup> In particular, transport is among the top three sectors in terms of the number of co-benefits that climate-related policies can offer. Similarly, in case of air pollution, there are many policies aimed at supporting technological advancements that can potentially lead to air quality improvements. This being said, the goal of these technologies is not typically environmental, but funding would be harder to attract if tackling air pollution had been the primary objective.

**Coordination across all environmental policies is needed to achieve tangible results on all fronts.** Reducing particulate matter, ozone, and greenhouse gases is essential to mitigating air pollution, including smog. It is important to identify the co-benefits in combating air pollution and other environmental issues, such as climate change, biodiversity loss, and address them effectively with specific policy instruments. Not only synergies but also trade-offs should be recognised. In order to do this, it is crucial to improve the collection and analysis of co-benefits and trade-offs data. The WHO, LSE Cities, and the C40 (among others) recommend developing a comprehensive policy framework which encompasses relevant sectors, and takes into account the interconnectivity of these issues.

**Air quality policies should be seen within the wider socio-economic spectrum so as to ensure that the measures implemented are adequate.** Under this banner, poverty requires particular attention. The EU Survey on Income and Living Conditions (EU SILC) estimates that 54 million European citizens (11% of the EU population, particularly in Central Eastern and Southern Europe) were unable to keep their home adequately warm in 2012. Similar numbers were reported with regards to the late payment of utility bills or presence of poor housing conditions.<sup>100</sup> Such wider socio-economic conditions affect both the supply and demand for policy instruments. In terms of supply, national and municipal governments need to ensure that command and control type instruments such as quality standards or bans are not burdensome for households (which in practice means that such instruments are ineffective). In terms of demand, this can mean that addressing the wider socio-economic issue may have to take precedence to ensure that the latter problem is effectively addressed.

**Additionally, greater coordination of international efforts is needed.** It is widely recognised that air pollutants can travel over long distances, especially ozone and particulate matter. This

means that besides the strong local component, air pollutants have an international impact, and need to be managed similarly to climate change so as to address these transnational externalities. Additionally, there are several issues such as quality standards that are most effective when agreed on the international level.

**It is important to bring scientists and policymakers together** – the success of the Gothenburg Protocol, which is recognised as one of the most effective environmental governance instruments, shows that having strong scientific and monitoring elements are very important. It enables policymakers to have sufficient insights into the facts and problems which guide their policy action, as policy-makers sometimes lack in-depth understanding of the key points. This means that without expert assistance, they oftentimes do not see the co-benefits and links with other issues.

**Effectiveness of national and municipal policies – experience shows us that government policy can help overcome market failures which contribute to the pollution problem.** Thermomodernisation programmes with a public support for the poor are good example of necessary cooperation between national and regional authorities. Of note is that it is advised that government intervention is only used to the extent that it helps solve the problem. For example, our literature review shows that in terms of air pollution originating from transport, the recommended policy instrument is registration tax, as it tackles the core of the problem, which is the purchase of polluting cars. However, this instrument is not able to influence emissions from existing vehicles. To solve this problem, registration taxes can be applied together with congestion charges on the municipal level, which apply to all vehicles and are able to tackle the distribution of emissions in time and space. Finally, it should also be noted that these instruments tend to have regressive effects (i.e. it affects people with low incomes more severely than people with high incomes).

**Cooperation with the private sector is key** – the examples of the Netherlands and Sweden among other countries, show that activating the innovate powers of the private sector is a key element of effective policies to address air pollution. These powers tend to be restrained under pure market conditions, and public investment to boost innovative solutions can increase the overall benefit to society. Local and municipal governments can also help incubate innovative solutions in research institutions, and connect them with business interests. Finally, they can facilitate partnerships between government, research centres, and the industry, thus creating conditions for high levels of innovation.



A hazy cityscape with a prominent church spire and modern buildings. The church spire is on the left, and several modern buildings are visible in the background. The sky is a pale, hazy blue, and the overall atmosphere is misty or smoggy.

# Potential technological solutions. Current state and development paths

This section of the report presents key technological solutions in the two sectors which are most central to the issues here discussed – namely transport and heating. For each technology, both the current state of development, and future outlooks are outlined. Additionally, key market challenges and business drivers are listed.

Analysis in this section is based on a technology tree, which was constructed with the help not only of thorough research, but also consultations with leading experts. Overall, the technology tree contains three levels, though for the purpose of the subsection on transport (5.1.) and heating (5.2.) only Level 2 (subgroups of solutions) is explored in depth.

Table 4. Simplified technology tree

Level 0. Areas	Level 1. Groups of solutions	Level 2. Subgroups of solutions
Transport	Electromobility and alternative fuels	Alternative fuel vehicles
		Alternative transport solutions
		Infrastructure for alternative fuels
	Technologies supporting modal, organisational and behavioural shifts	Traffic optimisation
		Last mile solutions
Heating	Increasing accessibility to low emission transport modes	
	Optimisation of combustion process	Optimisation of combustion process
	Energy efficiency	Insulation
		Efficient Energy management
	Grid, storage, and other integrating solutions	Smart Heat Grid
		Solar power efficiency
		Heat Storage
		Integrating solutions
	Heat generation	Heating from renewable energy
		Combined heat and power stations (CHPs)
		Heat pumps
		Energy recuperation
		4th and 5th generation networks
		Decentralised heat generation

Source: Analysis by Deloitte

Transport

Electromobility and alternative fuels

Alternative fuel vehicles

A significant reduction of air pollutants emitted by the transport sector can be achieved within the context of traditional internal combustion engine technologies. This has thus far been accomplished through the implementation of solutions focusing on energy efficiency and the reduction of emission-intensity, but it must also be noted that such improvements have proven to be limited by the technology itself. Thus, it is necessary to introduce a complementary strategy to facilitate the adoption of even lower-emission transport solutions. Making use of alternative fuels allows us to limit, or even fully eliminate the direct emission of certain air pollutants, while at the same time yielding energy savings. Alternative fuel vehicles can be defined as those which are at least partially powered by fuels other than petrol and diesel. This group includes both different types of electric vehicles (i.e. battery-electric, hybrids, and plug-in hybrids), as well as vehicles powered by compressed natural gas or biogas.

Current state and outlook

Although the market share of **hybrid electric vehicles** (which were the first modern mass-market alternative to conventional internal combustion engines) has increased over the last 20 years, and this shift is becoming more apparent, in 2015 only about 1.5% of new EU passenger cars were

hybrid-electric,<sup>101</sup> with **fully electric passenger vehicles** amounting to a further 1.2%.<sup>102</sup> Despite this dynamic development in the electric vehicle sector, the 2016 was the first year since 2010, when globally the market growth rate experienced a slowdown.<sup>103</sup>

Battery prices continue dropping

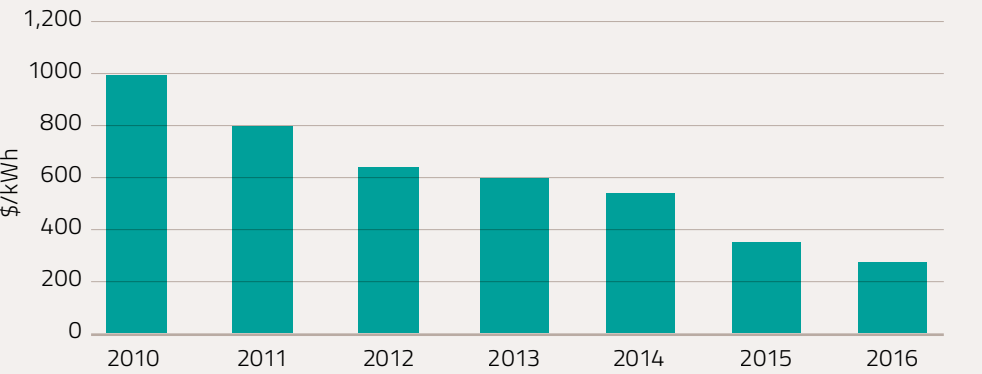
Batteries are the main reason why electric vehicles are more expensive than those equipped with internal combustion engines (ICEs), with the battery accounting for almost 50% of the retail price of an electric car in 2016.<sup>104</sup> Currently, there are three main families of battery technologies: conventional lithium ion, advanced lithium ion (with an intermetallic anode), and technologies which go beyond the lithium ion model (e.g. using lithium metal). The first type is by far the most prevalent at the moment, but the focus of the industry has been on developing the last type.<sup>105</sup>

Although battery technology is still overall in an early stage of development, production cost decline, technological

improvements, and economies of scale are all serving to drive battery prices down. Similar to the trend observed in photovoltaic technology, the decline in cost is much more rapid than expected. A recent survey by Bloomberg New Energy Finance (BNEF) has shown that the average price of lithium-ion batteries (cells plus pack) has dropped by 73% since 2010, meaning a compound annual change of -17%.

The 2016 US DOE target for 2020-2022 is to reach a battery cost of \$ 100/ kWh using lithium-metal technology, a cost level designed to achieve price parity between BEVs and ICEs. What is more is that the BNEF sees room for even further decline, forecasting a battery pack price of \$73/kW by 2030.

Figure 20. Lithium-ion battery price



Source: Analysis by Deloitte based on Bloomberg New Energy Finance

Nonetheless, the falling cost of batteries (from approximately 1,000 \$/kWh to 350 \$/kWh over the period of 5 years<sup>106</sup>), coupled with favourable regulatory conditions, have increased interest from major manufacturers, as well as states' engagement in shifting away from traditional internal combustion engines. Through the establishment of quantitative targets for electric vehicles, as well as the setting long-term phase-out targets for diesel and petrol cars, states have fostered market incentive, and prompted private enterprise to exploit this growing market. Current predictions show that by 2040, as much as third of the global automotive stock will be electric.<sup>107</sup> Another encouraging forecast is that although the current costs of electric cars exceed those of internal combustion engine vehicles, by 2030 they will likely attain cost competitiveness.<sup>108</sup> Simultaneously, lithium-ion battery demand is expected to increase from 21 GWh in 2016 to 1,300 GWh by 2030.<sup>109</sup> These developments (both political and economic), paired with recent technological advances, have substantially broadened even the potential near-term scope of application of electric drivetrains. Accordingly, several companies have announced widespread launches of **electric trucks** in the coming years.<sup>110</sup> Notably, this pioneering group of manufacturers

have already begun customer trials<sup>111</sup>, and the global market for this type of vehicle is expected to surpass 300,000 units by 2026.<sup>112</sup>

Two other emerging technologies that may influence the market of the alternative fuel vehicles are **hydrogen fuel cells** and **compressed natural gas (CNG) motors**. The issue which hinders the rapid adoption of these alternatives are significant upfront capital costs, which emerge from both the manufacturing of the powertrains themselves, as well as the construction of a refuelling infrastructure. The good news is that between 2006 and 2010 the unit cost of such vehicles halved, but unfortunately, since that period only marginal improvements have been made.<sup>113</sup> From this, it is easy to understand how although present projections<sup>114, 115</sup> envisage the deployment of over 1,735 fuel cell vehicles across Europe by 2022, substantial cost reduction and more market accustomization are needed to achieve this goal.

This being said, the overall demand for CNG vehicles is slated to increase, as part of a trend correlated with the ongoing ‘greening of gas,’ even though market share is still relatively low (0.7% of European registered vehicles in 2015).<sup>116</sup> This prediction is further solidified by the European Commission’s focus on the development of gas infrastructure, with applied forecasts projecting that the CNG vehicle market share has the potential to reach 10% by 2030.<sup>117</sup> Moreover, a rise in CNG vehicles will be facilitated by increasing interest from stakeholders in the gas industry, as well as an ongoing development of the CNG refuelling infrastructure.

*Market challenges and business drivers*

**The main market challenges include**

- High upfront costs compared with conventional vehicles. Mixed outlook: 1) rapid decrease in costs for electric vehicles thanks to technological advances and scale effects, and 2) other technologies are beginning to offer earnest competition.
- Customer’s range anxiety linked with limited availability of charging and refuelling infrastructure. Both a high frequency, and a high number of charging / fuelling points is a key requirement for the widespread adoption of alternative fuel vehicles.
- Electric grid capacity and interconnectivity. This is especially important in later stages, once we reach a tipping point in favour of such vehicles, as currently, there is a limited ability of existing grids to sustain the increased demand.
- Policy frameworks and standardization. There is a lack of flexibility engrained in current models, which are provided and promoted by existing manufacturers.
- High entry barriers for potential new producers.

**Business drivers for alternative fuel vehicles include**

- R&D activities contributing to a decrease in both the battery and energy infrastructure costs.
- As cost-competitiveness can be reached in the coming decade, there is a great potential for stakeholders to leverage the ‘first-movers advantage.’ This can be achieved through early know-how acquisition, and by securing a market share in the early stages of market development.
- Compliance with CO<sub>2</sub> and air pollution regulations – new, more stringent norms are continuously being implemented.
- Preferential administrative treatment for alternative fuel vehicle users (e.g. preferential parking permits, permission to use bus lanes etc.).
- Financial incentives (e.g. tax exemptions, subsidies, toll road charge waivers etc.).
- Potential for sector coupling (e.g. vehicle to grid solutions). This term is used to describe the removal of barriers between sectors, so as to optimize the generation, exchange, and use of energy. These efforts are most apparent in three major end-use sectors - namely heating, transportation, and power generation.

**Companies and solutions to watch**

1. Riverside (UK) – independent hydrogen fuel cell vehicle manufacturer offering circular service-based ownership model
2. Hyperdrive (UK) – high performance energy systems to power electric vehicles

3. Photofuel (EU) – further development of the direct fuel technology using photosynthetic microbiological cells

**Alternative transport solutions**

The increased use of private cars, related in part to ongoing trends in urbanization, as well as the falling cost of personal vehicles in relation to average earnings have led to ever-increasing emissions from the transport sector. The air pollution caused by the congestion resulting from more traffic can however be limited if innovative low emission transport solutions are implemented. The application of new ‘low’ or ‘no’ emission technologies might not only directly contribute to the reduction of pollutants, but might also indirectly improve air quality through a positive impact on the capacity of urban transport networks. This is to say that aside from the capacity to improve performance and efficiency of a given mode of transportation, these technologies might well change the *way* in which we get around.

**Current state and outlook**

Two main trends are currently on the rise – the electrification of transportation (e.g. **magnetic field trains, and electric waterway transport**), as well as the implementation of advanced solutions adapted to traditional means of transport (e.g. **high-tech buses and heavy duty vehicles**). In the case of the latter group, this often entails the implementation of complex electronic systems (telematics) which ensure connectivity to a network, resulting in an optimisation of internal processes through automation, as well as vehicle linking known as **‘platooning.’** Tighter exhaust gas regulations and access restrictions for diesel vehicles will result in demand for alternative drive systems, especially hybrid and LNG.

Although the first trials for the aforementioned solutions were held as early as the 1980s,<sup>118</sup> there have emerged only a very limited number of commercialised alternative transport solutions in the ensuing decades. For example, magnetic field trains function on a commercial level only in China, Japan and South Korea, and high-tech buses with self-driving capabilities, zero-emissions engines, and all sorts of innovations that makes them greener and more efficient, but also more attractive to riders, are only being used either in enclosed areas or on a trial basis (e.g. Singapore<sup>119</sup>).

*Market challenges and business drivers*

**The main market challenges include**

- Safety concerns relating to alternative transport vehicles, particularly the ability to ensure traffic safety with both automated and human controlled vehicles operating concurrently.
- Considerations relating to urban planning – undermining the economic case by necessitating large scale investments.
- High infrastructure costs – both in terms of new components, as well as integrating existing ones.
- Standardisation issues which involve everything from the distance between vehicles in the case of platooning, to overall system connectivity (in the case of high-tech buses).

**Business drivers for the alternative transport solutions include**

- Existence of a coordinated route for implementing electric vehicles – public transport enables us to trial technologies for automated vehicles in a relatively controlled environment, due to the structured nature of routes, systems (e.g. bus lanes) and infrastructure.
- Potential for a decrease in both the number of accidents, and as a result, insurance costs
- Reduction of primary energy demand
- Decreased congestion and traffic optimisation
- Efficient asset utilisation – reduced vehicle non-use time

**Companies and solutions to watch**

1. Alstom (France) – rail manufacturer that offers trains powered by a hydrogen fuel cell<sup>120</sup>
2. Torqeedo (Germany) – company offering hybrid powertrains for waterway transport<sup>121</sup>
3. Solaris Bus & Coach SA (Poland) – manufacturer of innovative public transportation vehicles and e-mobility solutions





### Norway plans to spend \$1 billion on bicycle highways

In order to combat air pollution, the Norwegian government has approved the National Transit Plan, whose main target is to cut CO<sub>2</sub> emissions by half by 2030. One of the initiatives proposed in the plan involves building 10 broad, two-lane, cross-country bike paths in and around Norway's nine largest cities. This will necessitate the allocation of \$923 million, with the proposal calling for 100% state-funding. The purpose of the new paths is to establish bicycle commuter links between inner cities and outer suburbs, thus extending the protected cycle network outside of the urban cores to which they are typically restricted. Other than better integrating urban and suburban regions, the commuter belt will allow cyclists to travel safely at speeds of up to 40 km/h. This plan fits well with the Norwegian government's goal of increasing the share of bicycle traffic to between 10 and 20 percent of the total volume by 2030 (up from about 5% today), perhaps a reason why this initiative has found so much official support. This is not to say that there is no resistance to the scheme, as commuter cycling in Norway is still relatively uncommon by Scandinavian standards (for their part, Danes make 17% of all journeys by bike). It has also been pointed out that the new highways will be constructed in a mountainous terrain that is cold and dark for most of the year – a reality which many claim will discourage

their use. As a repost to these criticisms, two points have been made that a cycle culture remains a possibility in Norway. Firstly, snow removal infrastructure is already present in the country, and secondly, Norwegians have a strong outdoor sporting culture which is not season-dependent. Supporters also point to the fact that other equally northerly locations such as Oulu, Finland, and Edmonton, Canada,<sup>122</sup> have maintained all-year cycle commuting through carefully maintained infrastructure. What is more is that the Norwegian transit minister has stated that he believes there might be an electric bike boom on the way.<sup>123</sup> For their part, the Germans are building the world's longest "bicycle autobahn" in the Ruhr region to connect 10 cities and remove as many as 50,000 cars from the road. With the popularity of e-bikes is growing in Europe, we may soon experience a new trend of long-distance cycle commuting – a trend which would be beneficial for both the population, and the environment. As encouraging as these developments may be, it still remains to be seen if the bicycle highways of Norway will become a reality, as the project is still in its formative stages. This being said, the idea of an oil producing country being committed to reducing its dependency on oil, and even going so far as to allocate its oil revenues to bike highways bodes well for the future.

### Infrastructure for alternative fuels

Underdeveloped infrastructure for the provision of alternative fuels has been identified as one of the main limiting factors for the widespread adoption of this class of vehicles. As more technologies that enable the use of alternative, low emission fuels reach the verge of being economically viable, the development of efficient, user-friendly infrastructure becomes a crucial component of ensuring the successful reduction of air pollution caused by transport.

#### Current state and outlook

As was mentioned, there is a strong need to ensure that the infrastructure can not only meet the increasing demand, but also boost future growth in the share of alternative fuel vehicles. In response to this need, there have emerged a number of projects such as **multiple car charging facilities** (e.g. charging towers – electric vehicle stack parking), and **fast chargers** that have the ability to charge vehicle in 20 minutes (providing a two-hour drive).<sup>124</sup> This enables quicker turn-over, and thus greater accessibility to the refuelling infrastructure. Importantly, many stakeholders have now prioritised the development of fast charging infrastructure, aiming to increase the capacity from 44 kW to 150kW, with one actualized demonstration project being able to achieve approximately 140 kW.<sup>125,126,127</sup>

The aforementioned technologies are in turn being paired with development strategies such as **charging corridors** (roads with recharging infrastructure being available at regular intervals), as well as **universal plugs for super chargers**,<sup>128</sup> and the establishment of more publicly accessible refuelling stations that share a common design and standardised equipment. Overall, it is hoped that this will bridge one of the main barriers of adoption, namely 'range anxiety,' or the concern about being unable to reach the next recharging station due to the vehicle's short range.

Despite growing demand for these solutions, the rollout of refuelling and recharging stations still needs a combination of both private and public financing, as well as regulatory pushes that ensure systemic transition.

#### *Market challenges and business drivers*

##### The main market challenges include

- Urban planning and regulatory limitations
- Grid and urban infrastructure limitations
- High infrastructure costs
- Competition between different stakeholder groups over the recharging/refuelling infrastructure

##### Business drivers for infrastructure relating to alternative transport solutions include

- Rapidly growing demand
- Favourable regulations; e.g. introduction of the requirement for new buildings to establish charging infrastructure on the premises
- Governmental subsidies; e.g. public parking schemes to include preferential terms for AFVs
- Utility-run frameworks
- Possibility of partnerships with local governments and OEMs

##### Companies and solutions to watch

1. Hygen (Latvia) – low-cost and convenient compressed natural gas home refuelling station
2. Ev-box (the Netherlands) – a charging station with fully modular construction ready to facilitate the expansion of the EV market
3. Volta (USA) – the largest free electric car charging network in the US

## A disruptive force on the fuel retail market

### The need

With more than 200 million households connected to natural gas distribution grids around the world, inexpensive and reliable CNG home refueling stations are a concept which has been pursued for some time now. However, due to high upfront costs, a short service life, and a lengthy refueling process (due to low velocity gas flow), existing solutions have proven unfeasible when practically implemented. NG is the lowest cost motor vehicle fuel available (>40% cheaper than gasoline), and emits about 30% less CO<sub>2</sub> than oil. This being said, lack of convenient infrastructure has resulted in it still being far from a preferred choice for end users. Currently, only 3.6% of gas stations possess NG infrastructure, in turn creating an opportunity to expand this network, thus capturing a part of the largely untapped EUR +30 billion suburban passenger car fuel market (currently served almost exclusively by conventional fuel service providers).

### The solution

HYGEN (HYdraulic GENerator) is a revolutionized gas compression system which employs patented multifunction liquid piston (MLP) technology. In comparison to mechanical compression (which is currently most widely used) MLP technology greatly reduces the time required to refuel from 10h to less than 10 minutes. Due to low number of moving parts, reduced friction between components, paired with minimal heat generation within the system, increases the service lifetime of units to 20,000h (approximately 4x longer than competing technologies). In addition to this, due to a completely reconsidered storage system, gas transfer efficiency sits at 98%, and provides 'fast fill' capability. What is more is that the components used in the production process are easily available on the market, thus making the product more affordable than conventional technologies. In case of failure, the system is also equipped with a modular design, and is thus easy to repair.

### Value proposition

The HYGEN solution has the potential to be a disruptive force within the energy market. It can be easily installed, and requires no additional investment as it integrates within existing gas utility infrastructure. It can reduce fuel costs by more than 40%, which adds up to around €10,000 savings throughout the lifetime of a vehicle. What is more is that HYGEN solutions benefit from low electricity consumption of 0.5 kwh/m<sup>3</sup>, and have the potential to reduce CO<sub>2</sub> emissions while simultaneously improving air quality (not mentioning the unique customer experience of quick, at home refueling). It must be noted that gas companies can profit on this solution through a resulting increase in gas consumption, as well as the creation of a regulated asset base.

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## Mobile CNG refuelling module

### The need

Natural gas, while being a much cheaper and more environmentally-friendly fuel than gasoline, has to address a major obstacle hindering the growth of CNG powered vehicles. This is the cost and availability of gas transport and fuelling infrastructure.

### The solution

GasLiner is a Latvian company offering an off-pipeline solution for CNG refuelling in which pipeline transportation is replaced with a fleet of mobile GasLiner trailers that deliver a continuous gas supply to customers, thus eliminating the need for both compression and unloading devices within the gas supply chain. This will serve to reduce the CAPEX of a virtual gas pipeline by 60% for gas companies and fuel retailers. With a transfer efficiency of 98%, the unit is capable of refuelling 50 CNG buses/80 dual fuel buses in 1.5 hours, or replace 8 public CNG filling points (800 nm<sup>3</sup> capacity each). This is due to the system's transport volume of 6400m<sup>3</sup> of Natural Gas or Biogas, and the fact that it requires no additional stationary infrastructure makes the technology even more flexible and efficient than existing solutions. The cost efficient operating range of GasLiner is up to 200 km from the gas source, which can be a gas pipeline, Biogas reactor or an LNG vaporizer. The total cost of the off-grid CNG filling infrastructure is estimated at € 0.30 nm<sup>3</sup>.<sup>129</sup>

### Value proposition

GasLiner is providing an innovative, cost-effective, convenient, and environmentally-friendly off-pipeline CNG refuelling solution. The benefits of GasLiner can be best used in places without a developed gas network, or those lacking CNG infrastructure. This will serve to combine the convenience of LNG handling, and the price point of CNG.

Source: TBB catalogue, 2017 edition

## Providing a smart energy supply for electric vehicles

### The need

Development and popularization of electric vehicles is dependent on the availability of fast charging infrastructure. The European Commission has proposed a minimum number of recharging points for each Member State based on the number of electric vehicles operated by 2020. However, installation costs for charging stations can vary significantly, depending on the distribution network characteristics, and can be very high in case of a highly congested grid in urban areas, or a low voltage grid in the countryside. This is not to mention places that are off-grid, requiring enormous additional investments.

### The solution

COFAST is a project for the development of an integrated EV fast charging station fuelled by a small-scale cogeneration system run on natural gas. The power output is estimated to be 142 kWe and 212 kWt, with a high energy efficiency of ≈90% and fast charging capabilities (≈50 kW). Apart from producing electric power, the system also produces heat energy that can be used to fulfil individual building needs, or to be injected into district heating networks. The system can have two configurations, either integrated or a modular. Both of these setups can be equipped with an optional Lithium Ion battery to optimize operation.

### Value proposition

The proposed solution delivers both environmentally-friendly and high energy efficiency fast charging stations with low grid impact costs. This will serve to reduce congestion on the grid by generating energy at the point of consumption. What is more is that the use of residual heat provides energy savings and CO<sub>2</sub> reduction, especially when compared with conventional configurations (consisting of a charger connected to the distribution network and heat generated via gas boilers). The system is decentralized, which also means that it does not require additional grid reinforcements, and has a payback time of approximately 8-10 years.

Source: TBB catalogue, 2017 edition



Technologies supporting modal, organisational and behavioural shifts

Traffic optimisation

The problem of an increased number of private vehicles on the road (and resulting air pollution), can be combated by either incentivising consumers to use public transport, or by increasing the efficiency of traffic management both at the network and individual vehicle levels. Looking more closely at the latter approach, we see that it is possible to minimise traffic-caused air pollution through both the provision of the enhanced transport network control system, or the implementation of systems that increase automation of the driving process. In both cases, there is an underlying goal of reducing inefficiencies associated with behavioural factors.

Current state and outlook

Reducing the number of driver errors may improve the overall transport system’s capacity through more efficient use of individual vehicles. This can be accomplished through the embedding of **advanced driver assistance systems** into vehicle’s structure. EU regulations have been working to facilitate a more rapid adoption of such technologies, by requiring all new cars by 2020 to be equipped with both an autonomous emergency-braking system, and a collision warning system.<sup>130</sup> This being said, although automated assistance solutions are currently being offered as an option on a wide range of vehicles, a lack of consumer awareness currently limits their widespread adoption.

Improvements in the efficiency in traffic flow can also be achieved by means of a comprehensive integration of **machine learning and big data** into the analytical processes that provide the foundation for traffic control. This, especially when paired with the establishment of **connected vehicle** networks, can supply data to traffic management systems more efficiently, and with greater precision than ever before. The development of an **intelligent traffic system** is widely regarded as the first milestone in automated mobility,<sup>131</sup> as it would harness both the potential of IoT and data provided by the network’s users so as to create a virtually omnipotent overview of traffic flows within an urban area. Available estimates show that intelligent traffic systems might be able to improve the efficiency of traffic flow by as much as 8%.<sup>132</sup> Not surprisingly then, the implementation of such systems are currently a primary objective of numerous municipalities, and they are also strongly endorsed by numerous EU frameworks.

A GPS based Traffic Control System will manage road congestion in Singapore

Electronic Road Pricing (ERP) is an electronic toll collection system used in managing road congestion in Singapore during peak hours. The scheme is based on electronic gantries placed over the roads at designated locations, along with In-Vehicle Units (IU), which are devices attached to the windscreens of cars. When a vehicle equipped with an IU passes under an ERP gantry, a road usage charge is deducted from the CashCard associated with the IU. The charge for passing through a gantry will vary depending on both the road and time of day, with peak hours being the most expensive.<sup>133</sup> Tolls range from \$0.50 to \$5.00,<sup>134</sup> and altogether, the ERP system collects approximately \$150 million annually. Following the introduction of the ERP system, the Land Transport Authority in Singapore reported that traffic congestion decreased by nearly 25,000 vehicles during peak hours, with

average road speeds increasing by about 20%. Additionally, overall traffic has gone down by about 13%, with vehicle numbers dropping from 270,000 to 235,000. It has been further observed that car-pooling has increased, while the hours of peak traffic have gradually eased in intensity, instead dispersing into off-peak hours, suggesting a more productive use of road space.<sup>135</sup> Although ERP has in practice contributed to managing traffic congestion, the system has limitations, particularly with regards to larger numbers of vehicles. As a result, the government is already working on the next-generation of ERP system, which will make use of a Global Positioning System (GPS), and allow for more flexibility in managing traffic congestion through distance-based road pricing. It will also be able to overcome the constraints of physical gantries, which are costly, and take up valuable land.<sup>136</sup>

Market challenges and business drivers

The main market challenges include

- Lack of existing consumer infrastructure and awareness
- Lack of standardisation of software systems enabling the inclusion of all vehicle types into the communication network; lack of legal framework
- Limited upgrade possibilities of existing infrastructure – high costs of refurbishment of and integration with the available systems
- Cyber-security and privacy issues; extensive need for data sharing for the system to be efficient
- Limited functionality of sensors and the need for complex integration of different technologies (processors, software algorithms etc.)

Business drivers of the infrastructure for alternative transport solutions include

- Increased consumer demand for, and awareness of road-safety features; co-benefits for customers (e.g. lower insurance costs)
- Dynamic development of IoT and data management
- Compliance with existing EU regulations
- Multiple applications and co-benefits (safety, environmental etc.) allow for a complex network of partnerships; opportunities related to integration with Original Equipment Manufacturers
- Partial automation as a foundation for implementation of fully automated vehicles

Companies and solutions to watch

1. Greinon (Sweden) – company that develops and commercialises control systems (mainly lighting control technologies) that can be applied among others to efficient traffic management
2. BestMile (Switzerland) - cloud-based company offering a fleet optimization platform for autonomous vehicles



Paris shows that comprehensive transport policy pays off

Paris is a metropolis - with 11.8 million inhabitants living in the Île-de-France region, the city is the most densely populated area in France, and as such, is heavily impacted by traffic congestion as well as pollution. The city’s air quality is among the worst in Europe – exposing the 90 percent of Parisians living within the city’s limits to polluted air on a daily basis. Motor vehicles are the main contributors to the air quality problem, producing a full 66 percent of Paris’s nitrous oxide emissions, and 56 percent of the particle pollution. Additionally, Parisians are spending 40 minutes in traffic each day, costing the city an estimated \$11.7 BLN in 2013 alone. Many different actions have been undertaken to mitigate traffic congestion and pollution in Paris. In 2017, Paris became the first major city with a restricted traffic zone, setting the precedent for a top-down approach originating with municipal authorities to resolve the problem. Another such initiative is the clean air sticker (Crit’Air) that drivers must display on their windscreen to show how polluting their vehicle is, and thus to restrict the use of vehicles exceeding certain emission limits. In addition to these measures, Paris offers subsidies to those who wish to replace their current vehicle with an electric or CNG substitute (up to a limit of 9000 EUR or 15% of the purchase price). In terms of infrastructure, Paris has worked on further

developing a varied public transportation network, including 16 metro lines, public bike sharing (23000 Velib’), public EV sharing (400 Autolib’ and about 800 charging stations), as well as more than 700km of bicycle lanes in order to encourage commuters to opt for enviro-friendly commutes. Another move designed to reduce congestion and simultaneously improve road safety is the removal of traffic lights from certain streets. A predicted 200 intersections will be stripped of their lights by the end of 2018. The aim of this new scheme is to make drivers more aware on the road as well as other users, and also to reduce traffic jams as well as accidents. In the last 25 years, the reduction in traffic congestion has been remarkable. The share of cars in the total traffic makeup within the city limits has dropped by 45%. Public transport use has increased by 30%, and the number of cyclists has multiplied 10 fold. Pedestrian safety has also improved with the introduction of central islands and raised crossings. This being said, even with the aforementioned successes, the city still faces a pollution issue, as the main culprit is the unrestricted use of diesel engines. Until recently, the French government subsidized diesel fuel, but today, the goal is to ban the sale of vehicles powered only by fossil fuels by 2040.



### Last mile solutions

With the increased use of roboticized manufacturing, and the introduction of limited run, targeted consumer trends in the 1970s, there has been a seemingly perpetual march toward individualized solutions – a trajectory which has become amplified in the digital age. The insistence of the consumer on personalized products and services has severely strained our transportation by-ways, a problem which has been compounded by online retail and a market requirement for the rapid transport of goods. In other words, to satisfy the desires of the individual, we have had to compromise our urban environment – our interactions with both environment and infrastructure are in dire need of fundamental rethinking.

One of the trends in innovation which seeks to renegotiate how we think of and use our physical infrastructure are last-mile transport solutions. These seek to both improve the consumer's traveling experience, and provide incentives to use alternative modes to private vehicles. The idea is to also increase the efficiency of delivery services, while simultaneously reducing any negative environmental impact.

#### Current state and outlook

Today's vision of a last mile transport and delivery model is likely to be dominated, or even replaced by **autonomous vehicles**, which have in recent years been gaining momentum. Despite the uncertain legal frameworks surrounding unmanned vehicles, leading delivery-service providers have already identified opportunities arising from the use of self-driving vehicles in the context of a last-mile delivery system.

Larger scale automation (e.g. **automatic guideway transit**), which may boost the demand for public transport, is currently strongly dependent on public policies as well as governmental subsidies, and as such only several large-scale projects have become operational (e.g. London's Docklands Light Railway Tram).

Moreover, many companies have now realised that **car-sharing services** can provide an answer to the last-mile challenge. The car sharing market is developing dynamically, with the number of communal vehicles experiencing more than a two-fold increase in recent years.<sup>137</sup> As discussed earlier though, further innovations are needed for low-emission vehicles to account for a greater share in the shared car fleet. Recent trial schemes introduced coordinated sharing of ultra-compact electric vehicles,<sup>138</sup> as well as new business models involving cooperation between car sharing operators and public transport providers.<sup>139</sup> These projects aim at increasing the accessibility of public transport, however the wide scale implementation of such schemes has not yet occurred.

#### Market challenges and business drivers

##### The main market challenges include

- Stringent regulations that limit experimental delivery modes to constrained trial areas
- Integration with existing infrastructure – last mile solutions are not a self-sufficient component of the transportation sector
- High infrastructure costs
- Lack of standardisation
- Safety concerns

##### Business drivers of the infrastructure for alternative transport solutions include

- Growing consumer demand for personalised services, as well as rising public acceptance for autonomous vehicles
- With increasing labour costs, implementation of the autonomous vehicle becomes economically attractive alternative to traditional delivery mediums
- Optimisation of resource use and increased efficiency of services
- Financial incentives, e.g. parking fee exemptions;

### Companies and solutions to watch

1. Navya (France) – driverless vehicles for the specific site transportation of goods and people
2. EasyMile (France) – shared driverless transport solution for the last mile

### Automatic guideway transit at a glance

Automated guideway transit (AGT) is a category of advanced transportation technology that is primarily characterized by being both fully automated and driverless. It runs on a dedicated circuit which does not interfere with other modes of transport. Due to its simple design, AGT does not have the same constraints as metro. Today about 800km of automated metro and tram lines are operational and according to the UITP, by 2025 this number will increase to more than 2,300km. Asia and Europe are expected to account for 33% and 30% of driverless transport lines, followed by the Middle East (25%) with ambitious projects such as the Riyadh transportation system. Increasing urbanisation requires optimization of current transport infrastructure so as to handle more passengers at limited capacity, without possibility of extension in congested areas. Automated mobility solutions can be the answer to this challenge offering high headway up to 60 seconds (Lille's metro), high flexibility enabling real time demand response and high commercial speeds (up to 44km/h in Vancouver) while reducing

operating costs (by up to 40%) due to human resources flexibility. Even though the technology has been around for some time as world's first mass transit AGT was established in Kobe in Japan in 1981 connecting city's main rail station with the dockyard area and the airport, today France is leading the driverless mass transport operations having autonomous transit infrastructure in their major cities (Paris, Lille, Lyon, Rennes, Toulouse). Summing up, driverless transportation systems can overcome the congestion challenges in densely populated areas in Europe as well as in emerging countries of Asia and Africa. Once limited to larger airports and a small number of metro systems, AGT have developed rapidly since the late 1990s. Lower capital costs compared to conventional metros have allowed AGT systems to expand quickly in the era of smart cities becoming a real alternative to conventional metro lines.

Source: <https://www.wavestone.com/app/uploads/2017/04/driverless-metro-lines-world.pdf>



Evolving urban mobility

The need

In order to mitigate climate change and improve air quality, policy makers around the world are aiming to ban cars in cities, and gradually shift toward environmentally-friendly modes of transport. On the other hand, the strain on urban transportation networks is growing, and there remain no efficient alternatives to traditional cargo vehicles.



Source: TBB catalogue,2017 edition

The solution

The Evolo system incorporates some of the latest technological advancements in the field of transportation, and is dedicated to the development of sustainable urban mobility solutions. Their main product is a power assisted tricycle that can carry up to 250 kg at a cost of 0.2 EUR/100km. This is accomplished without any direct fuel consumption, and minimal environmental impact, while still offering a maintenance cost that is less than 1 euro per day. According to Evolo, the efficiency of their cargo tricycles is unattainable by traditional motor vehicles – no matter how much we might improve on existing technologies. A trike can make 1,500 stops per month, while a van can hardly reach 835 stops, and an Evolo product is able to circulate on all kinds of infrastructure (pedestrian and urban roads). What is more is that they are not subject to the same time restrictions for loading and unloading in pedestrian areas. Last but not least, the tricycles’ easy operability and driveability reduce delivery and unloading time to a minimum, and additionally, Evolo offers after-sales support.

Value proposition

Evolo is proposing a cost-effective and sustainable solution that improves existing urban transportation logistic business models, and enables public and private institutions a strategic implementation of sustainable urban mobility projects. This will have the knock-on of allowing stakeholders to save on existing inefficiencies (time ranges and accessibility), as well as other associated costs such as fuel and vehicle expenses (acquisition, maintenance and insurance).

Increasing accessibility to low emission transport modes

Increased use of private vehicles, congestion, and resulting air pollution can be addressed with technologies that incentivise behavioural change, and promote the use of public transport. Solutions that improve user experience, as well as make that troublesome commute more convenient play a significant role in embedding low emission transport into urban travel patterns. Some public authorities have already implemented policies that aim to increase the use of public transport by making it more accessible (e.g. lowering or completely removing fares during the days with high air pollution). It is hoped that by complementing such regulations with the widespread implementation of innovative technologies will allow us to sustain the ease of access on an every-day basis.

Current state and outlook

Although technologies that enable the digital management of public transport tickets exist in many cities (London, Madrid, Warsaw), innovations are needed to ensure interoperability and greater flexibility of one digital wallet. The overarching goal is one system which can manage several tickets for different regions, modes of transport and distances, commonly known as **smart ticketing**. Similarly, **smart automated interchanges** have already become an integral part of network operators’ strategies to encourage consumers to use publicly provided transport services. Importantly, these technologies serve as examples of solutions that not only simplify the commuting experience (easily accessible information regarding the fares and connections even in the remote areas), but also quicker (due to the automation of processes and transfers),

and cheaper (through enabling tailor-made fare options). Other than all of this, they allow for the consumer to more easily connect between different modes of transport, thus playing a significant role in making the transportation sector more usable on a large scale.

In conjunction with the above solutions, infrastructure that limits the hassle of a ‘no-emission commute’ is contributing to the increase in consumer demand for environmental-friendly travel solutions. Examples of such supporting developments include **automated cycle parking that allows** consumers to deposit their bicycles in the autonomously operated under- or over-ground vaults, and **mobile device applications** that allow for the easily access, and optimal use of low-emission transport.

Market challenges and business drivers

The main market challenges include

- Solutions are often an integral part of the urban transport network, hence their operation is dependent on development of the transport infrastructure
- Lack of consumer technological capabilities and awareness
- Cyber-security; personal data management needed for tracing user’s journey
- Different expectations and requirements from different stakeholder groups

Business drivers for the infrastructure for alternative transport solutions include

- Increased consumer demand for personalised services, real time information
- Increased consumer awareness of benefits of sharing economy
- Decreased operational costs; greater availability of smart devices
- Limited infrastructure requirements to successfully implement certain new solutions
- Public transport operators’ demand for solutions that allow to decrease congestion

Companies and solutions to watch

1. Masabi (UK) – platform that aims at simplifying ticketing and streamlining fare collection, validation and management for transport providers across all modes of public transportation
2. Jiffi (Estonia) - Hands-free mobile ticketing & validation for public transit
3. Skycash – universal system of mobile payments

Heating

With increasing consumer awareness regarding the impacts of air pollution arising from the combustion process (which accounts for the majority of energy used in heating and cooling) comes a demand to decrease its negative impacts on both the environment and health. This requires adoption of diversified technologies that allow us to not only increase heating efficiency, but also achieve zero-emission heating solutions, thus limiting the resulting contaminants.

Optimisation of combustion process

Currently, conventional furnaces and boilers are the most dominant technologies used for heating purposes in most OECD countries.<sup>140</sup> Although other low emission heat generation technologies are being dynamically developed, the transition to, and full adoption of new solutions is a timely process. Thus, it is first necessary to decrease primary energy demand, and improve the efficiency of the combustion-based technologies currently in use so as to limit emissions. Any solution that allows for the reduction of airborne toxins from the combustion processes will need to improve both the combustion conditions themselves, as well as touch on technologies implemented at the post-combustion stage (e.g. scrubbers, filters, catalytic destruction, precipitators).

Current state and outlook

**Gas adaptive systems** serve as an example of the innovation that is currently becoming more common in domestic furnaces, allowing for substantial, immediate improvements. This solution

introduces an automatic mechanism that, by monitoring the quality of combustion process, can optimise combustion according to the type of gas that is being supplied.

Similarly, replacement of flame combustion with **catalytic combustion in biomass stoves** offers great gains in efficiency, with improvements of between 70% and 80%,<sup>141</sup> as well as a reduction of up to 55% in terms of particulate matter.<sup>142</sup> What is more is that further technological improvements in high-efficiency catalytic combustion biomass stoves are predicted to decrease particulate matter emissions by 60 to 90%.<sup>143 144</sup> Importantly, innovative solutions such as catalytic dampers can be easily added on to already existing stoves, with such technologies significantly reducing the costs of retrofitting.

*Market challenges and business drivers*

**The main market challenges include**

- Lack of consumer awareness regarding technological developments; high costs
- Well established existing infrastructure
- Large competition – difficult to achieve competitive advantage for new market entrants

**Business drivers include**

- More stringent environmental regulations and air pollution emission limits
- Increased consumer awareness vis-à-vis health issues related to air pollution
- Efficiency gains – potential for customers to reduce primary energy demand and costs

**Companies and solutions to watch**

1. Siemens Combustion Optimisation – an online hybrid control optimizer using neural network
2. NeuCo CombustionOpt – optimization of fuel and air mixing by manipulating relevant fuel and air injection points in real time to reduce NOx and other emissions and improve fuel efficiency

**Energy efficiency**

**Insulation**

As part of one of the running themes of this report, an effective way of limiting air pollution is to reduce demand relating to energy consumption, and thus of the fuels underlying the release of particulate. In the built environment, insulation reduces heat loss / gain, thereby allowing us to reduce how much we have to heat in the first place. This in turn reduces our dependency on the fossil fuels most likely to contaminate our air, all without compromising the comfort of a buildings occupants. What is more is that aside from increasing the energy efficiency of the building sector, insulation both enables, and facilitates the integration of other low emission technologies (e.g. PCM materials), a fact which makes a focus on not only the generation of heat, but also its retention imperative to any successful overarching strategy.

**Current state and outlook**

Although many insulation techniques have existed for decades, recent innovations in material processing technologies, as well as technical developments within certain existing systems have allowed for dynamic changes in the building insulation material market. Technologies such as **vacuum insulation panels** allow for up to a ten-fold increase in thermal insulation capacity, when compared to traditional solutions. Research shows that **aerogels** are capable of ensuring an efficiency of building insulation even 40 times higher than that provided by conventional fiberglass technology,<sup>145</sup> although their use is currently limited to specialized applications. Current innovation activities are also focusing on the implementation of **insulation technologies which make use of noble gases** to further reduce the heat exchange between in-door and out-door spheres. Similarly, **phase change materials** (PCM) have been tested for more than ten years, with case studies demonstrating that the use of PCM can lead to energy savings of between 20% and 40%.<sup>146</sup>

*Market challenges and business drivers*

**The main market challenges include**

- High material costs
- Well established traditional technologies
- Scale effects translate into high barriers for new market entrants
- Lack of awareness among small-scale developers

**Business drivers for innovative insulation solutions include**

- Need to comply with stringent EU energy efficiency targets
- Dynamically developing nano-technologies
- Synergies with novel heat generation technologies, allowing us to balance heat demand with own supply based on low-emission microgeneration and/or next generation heat networks
- Demand for innovations by the ESCO (Energy Service Companies) sector; specialisation of services provided by ESCOs and their innovative financial models allow for a large investments which can translate into the quicker uptake of new insulation technologies

**Companies and solutions to watch**

1. Active Insulation (the Netherlands) – Active Insulation develops switchable and intelligent insulation to cool and heat buildings by natural processes
2. NexAero (Switzerland) – insulation with aerogels

**Improving our health through building energy renovation**

In order to realise Europe's contribution to the Paris Agreement, the rate and depth of building energy renovation needs to triple. Stimulating such demand requires people's health and wellbeing to be a core priority. It also requires the availability and access to affordable and highly efficient housing and clean energy services. Europeans spend 90% of their time indoors. Yet, there is little awareness about how the quality of our buildings affects our health and what we can do about it. Bad quality buildings contribute to air pollution through high energy demand and inefficient boilers. Energy use in buildings is responsible for 36% of CO<sub>2</sub> emissions, 50% of particulate matters and 50% of CO emissions in the EU. In Poland, for example, 60% of households burn coal and waste in solid fuel stoves to heat their homes to save on energy bills while also creating a massive air pollution problem for the region. Breathing the winter air in city of Cracow is equivalent to smoking 2,500 cigarettes every year.

While outdoor air pollution presents a problem for health, poor indoor air quality can cause allergies and asthma while those who live in the coldest homes are three times more likely to die from cold-related illnesses. The World Health Organisation estimates that healthier homes and work places could prevent 1 million deaths globally per year. Across Europe, between 50 and 125 million people live in energy poverty. These are often households that live in poor quality buildings with leaky roofs and/or mould and rotting walls or foundations. We have the technology and know-how to make all homes and buildings healthy and comfortably warm (and cool) while consuming net zero energy. However, more innovation is needed to bring down the cost and develop consumer-oriented business models that finance and deliver net-zero-energy renovation.

Patty Fong  
European Climate Foundation

**Efficient energy management**

Since heating and cooling processes drive most of the energy demand of urban infrastructure, any reduction of energy consumption will require us to implement comprehensive solutions at both supply and demand ends, in a 'front to back' crackdown on systemic inefficiencies. In this vein, it is envisioned that building energy management systems will complement smart energy grids, and allow for end users to both control and monitor their energy consumption. Detailed, disaggregated data received by consumers will enable efficient management of building loads, and enable the establishment of energy management strategies that respond to the actual usage patterns. Moreover, automated infrastructure and digital connections will allow consumers to make decisions, and implement proactive strategies based on real-time price data, as well as their



personal preferences, whilst reducing systemic inefficiencies relating to subjective human factors and behavioural barriers (e.g. lack of awareness, time, skills).

#### Current state and outlook

Efficient energy management is being made possible due to the increased availability of technologies such as **smart meters or home automation networks**. The uptake of such solutions has been associated with the development of smart infrastructure, and facilitated by government subsidies. Energy savings can also be ensured through the integration of **demand controlled ventilation** into HVAC (Heating, Ventilation and Air Conditioning) systems. The gains resulting from this configuration are dependent on the occupancy level, and can be substantial if there is wide variation in its density with a building. Further improvements in device connectivity and flexibility will allow for a complex integration of localized heat management systems within the overarching smart heat and power grids. This will prove essential to efficiently addressing issues related to aggregate demand, and thus the optimisation of resource allocation by utility operators.

#### *Market challenges and business drivers*

##### The main market challenges include

- Multiple stakeholder engagement; lack of uniform standards
- Lack of consumer awareness and technical capabilities
- Potential limitations resulting from lack of flexibility in the existing built infrastructure
- Personal data and cyber-security issues
- Complex grid integration process
- Issues with ensuring system interoperability and integration of different technologies

##### Business drivers for efficient energy management include

- Dynamic development of smart grids and green office buildings
- Increased demand for personalised solutions
- Optimisation of resource use
- Stringent building energy efficiency norms
- Dynamic development of IoT and cloud technologies that facilitate efficient energy management

##### Companies and solutions to watch

1. Betterspace (Germany) – integrated hotel optimisation solutions – smart room heating control
2. SystemGenius (UK) - wireless, remote heating control system for buildings that allows for the independent control of different zones within buildings
3. BTA Climate-KIC (Switzerland) – supports the development of innovative building technologies, construction services and businesses with an aim to reduce CO<sub>2</sub>
4. Coturnix (France) - optimization of the energy consumption and associated costs in real time, based on the mathematical model of building “behaviour”

## Grid, storage, and other integrating solutions

### Smart heat grid

As we have seen, the implementation of technologies that increase the efficiency of, and demand on district heating grids can also allow us to more accurately manage energy demand, and thereby limit energy consumption. In terms of an overarching strategy, this is particularly relevant, as heating and cooling processes used in households and by industry currently account for 50% of the EU’s annual energy consumption. Macro-solutions which also enable smart, demand-driven heat distribution will thus contribute to the decrease in fossil fuel energy dependency, and thus associated air pollution.

#### Current state and outlook

Improvements in district heating grids leading to the establishment of smart heat grids are currently a strategic priority of many European cities. Currently, stakeholders focus on the development of measures that would allow for efficient demand side management – technologies



such as **smart heat meters**. Similarly **distributed heat generation**, which is facilitated by the increasing market share of renewable energy, is the focus of ongoing innovative activities. Both of these development strategies are endorsed by the EU Heating and Cooling Strategy.

In the process of establishing smart heating grids, a great deal of focus has been placed on the **incorporation of different heating technologies**. This is mainly due to the fact that currently, best achievable results come as a product of pairing the use of renewable technologies with CHP, and advanced heat pump technologies. This formula has been so successful due to its ability to address the mismatch between supply and demand brought about by the intermittent nature of renewable energy sources. What is more is that numerous case studies (e.g. Copenhagen, Hafencity and Stockholm) prove that a successful implementation of smart heating grids is currently strongly dependent on government subsidies, which tend to encourage changes of hardware. Although seemingly problematic, such ‘demand pull’ resulting from governmental policies is likely to catalyse the developments needed for technologies to reach their technical maturities. This process will also serve to increase consumers’ and utility managers’ awareness of multiplier opportunities that such solutions may offer.

#### *Market challenges and business drivers*

##### The main market challenges include

- Cyber security issues; risks related to personal data sharing
- High initial costs of implementation
- Low flexibility / adaptation potential of existing infrastructure
- Reliability of existing heat system – high consumer expectations regarding the continuity of heat supply
- Lack of standardisation and / or regulatory framework to facilitate adoption
- Complexity of interactions between different stakeholders and technologies

##### Business drivers for smart heat grids include

- Demand for integration of heating infrastructure with smart electric grids – consumer demand for efficient, simultaneous management of all utilities resulting from consumer preferences regarding smart infrastructure, and opportunity costs related to the coordinated upgrade of infrastructure
- High interoperability of technologies
- Increasing demand for the grid to integrate intermittent energy resources
- Broad stakeholder engagement – potential for cost burden sharing
- Financial incentives related to lower energy demand
- Compliance with the EU regulations
- Possibility of real time management of heat demand / peak load demand – more accurate demand/supply management
- New markets and services – especially those related to the next generation district heating

##### Companies and solutions to watch

1. DC Brain (France) - Artificial Intelligence tool for complex network managers (incl. gas, electricity, water, logistics)
2. EnergyVille (Belgium) – STORM: Self-organising Thermal Operational Resource Management – district heating and cooling controller based on self-learning algorithms

Solar power efficiency

As the EU’s construction sector transitions toward (nearly) zero energy buildings (ZNEs), this shift is likely to be accompanied by an increase in the demand for technologies allowing for heat generation from solar power. As such, it is safe to assume that improvements in the efficiency of technologies which allow for the harnessing of solar energy for heating both air and water are needed. The increased efficiency of existing systems, as well as their more widespread adoption can be advanced through both innovations in light absorbing materials, and through improved system mounting technologies.

Current state and outlook

Solar-thermal systems are a well-developed field, and as such, are regarded as a mature technology. This being said, their integration into built infrastructure is still limited, thus offering a great potential for further development. Since the early 2000s, solar heating and cooling capacity has experienced a seven-fold increase globally,<sup>147</sup> and a further 45% growth in this space is forecast by 2020.<sup>148</sup>

Currently, two systems are the most popular – namely ‘flat plate,’ and ‘evacuated tube’ collectors, with the former dominating the European market. Available case studies show that new shapes and **mounting solutions** need to be developed to enable a comprehensive integration with existing infrastructure.<sup>149</sup> In aid of this necessity, dynamically developing nano-technologies will allow us to increase the sunlight to heat conversion efficiency of **light absorbing materials**, with the newest laboratory-based developments reportedly delivering efficiency above 90%.<sup>150</sup> Special focus also needs to be placed on the development of new components such as absorber coatings and polymers.

Another area of special focus for R&D in the solar field relate to arrangements in which **solar-thermal systems are integrated into hybrid PV-thermal systems**. Besides the efficiency gains that they offer (about 40%<sup>151</sup>), the merger of photovoltaic and solar-thermal collectors enhances chances for the uptake of these technologies, particularly in urban environments where space is limited, and infrastructure is less flexible.

Market challenges and business drivers

The main market challenges include

- High upfront installation costs; high integration costs
- Lack of public awareness
- Limited flexibility of solar systems
- Space and infrastructural limitations
- Intermittent nature of solar energy
- Need for highly skilled professionals

Business drivers for solar power include

- Low operational costs
- Opportunity to combine units with energy storage units
- New business models – modular and simplified design allows for customer based solutions
- Widespread subsidy and grant schemes
- The EU targets for share of renewables in the energy mix

Companies and solutions to watch

1. Heliac (Denmark) – cost-efficient polymer foil based solar concentrators for utility-scale installations
2. Base (France) – Cogen’Air technology allows for simultaneous heat and power generation from the same solar panel<sup>152</sup>
3. Solabcool (the Netherlands) – cooling system that applies principles of solid sorption to utilize the waste heat



Light absorbing materials

The need

Solar radiation is a part of the electromagnetic radiation emitted by the Sun and is divided into ultraviolet (UV), visible and infrared (IR) light. The current challenge in solar utilization is how to effectively convert full-spectrum sunlight into directly available thermal energy at high conversion efficiency.

The solution

Plasmonic materials are nanostructures that can provide scattering, absorbance and coupling properties in light-matter interactions. These materials can strongly concentrate light within a nanoscale volume and generate heat by resistive losses when the irradiation wavelength reaches the plasmon resonant wavelength. Due to their high absorption in the near-infrared radiation (NIR) region and high solar-thermal conversion efficiency they can provide heating for the surrounding. In addition, at the same time, the nanoparticles can intelligently control the IR transmittance depending on the irradiation intensity and ambient temperature becoming an effective cooling solution.

Value proposition

The development of the nanoparticles that can convert light into usable energy will enable production of special materials and coatings that can be used as heating and cooling solutions improving buildings’ energy efficiency.

Source: VO2/TiN Plasmonic thermochromic Smart coatings for Room-Temperature Applications, Advanced Materials, January 2018

PV and hybrid PV power generation

The need

Given concern over air quality and global warming, there are significant policy efforts to increase renewable penetrations. Renewable energy technologies offer a source of power and energy security in communities and businesses operating in remote areas or difficult terrain. Solar power generation can help countries meet their sustainable development goals through provision of access to clean, secure and reliable energy sources. Today, photovoltaic technology is one of the fastest growing renewable energy sources and is expected to play a significant role in the future energy solutions. However, the challenge is to overcome its current efficiency and performance limits while decreasing production costs. Particularly, intermittent power generation technologies cannot ensure a reliable and clean electricity supply.

The solution

Hybrid PV power plants offer a range of feedstock and capacities. They can comprise a micro grid with several different types of generation working as an integrated unit or can occupy a single site. Typically, hybrid PV generation use a solar energy and a fossil fuel such as diesel or gas. Some, combine solar energy source with battery storage to minimize consumption of carbon based expensive fuels. In Nevada is unveiled world’s first triple geothermal-PV-solar thermal power plant – Stillwater power plant that will be key to the development of other hybrid plant throughout the world. ;Saulé Technologies is developing and commercializing an industrial production method of ultrathin, flexible third-generation solar cells based on solar energy harvesting materials – perovskites. Perovskites have structured compound, usually a hybrid organic-inorganic lead or tin halide-based material. Perovskites materials can be simple to manufacture and cheap to produce because so little material is needed. The injet printing techniques is used to design perovskite solar modules which allows for the diversity in sizes and shapes.

Value proposition

;Photovoltaic cells from perovskite offer new opportunities for architects and construction companies wishing to use solar energy. Solar modules are lighter, thinner and much more flexible in the design dimension than the most popular silicon cells. The shape, colour and size of the modules can be adjusted to customer needs and installed on every available building surface, not necessarily on the roof. Perovskite solar cells can generate power even when illuminated by artificial/ low light sources. ;Although solar PV offers cheaper power during the day time, it requires the support of the sustainable power generation technologies to provide round the clock power. The result of incorporating different energy technologies in hybrid power generation is the performance that exceeds the sum of its parts, both in plant’s ability to manage and utilize the renewable sources and in overall output.

Source:  
<http://sauletech.com/>  
<https://www.nrel.gov/pv/perovskite-solar-cells.html>  
[https://www.enidaily.com/en/technology\\_en/hybrid-power-plants/](https://www.enidaily.com/en/technology_en/hybrid-power-plants/)  
[https://www.pv-magazine.com/2016/03/30/worlds-first-triple-geo-pv-solar-thermal-power-plant-unveiled-in-nevada\\_100023938/](https://www.pv-magazine.com/2016/03/30/worlds-first-triple-geo-pv-solar-thermal-power-plant-unveiled-in-nevada_100023938/)  
[https://www.leg.state.nv.us/App/NELIS/REL/79th2017/ExhibitDocument/OpenExhibitDocument?exhibitId=30862&fileDownloadName=0411ab52a\\_pagt.pdf](https://www.leg.state.nv.us/App/NELIS/REL/79th2017/ExhibitDocument/OpenExhibitDocument?exhibitId=30862&fileDownloadName=0411ab52a_pagt.pdf)

Heat storage

Thermal energy storage (TES) technologies allow us to store excess energy for balancing the mismatch between day- and night-time, or summer- and winter-time energy demands. TES has two main advantages: firstly, it allows for a more comprehensive use of renewable energy sources, and secondly, through the application of TES solutions, it is possible to mitigate the peak demand, thus levelling the load.

Current state and outlook

The three main types of thermal energy storage include: **sensible heat storage, latent heat storage, and thermochemical heat storage**. The latter two are still currently regarded as emerging

technologies, with application of **phase changing materials** finding application mainly as a part of trial projects, and with **thermochemical energy storage**.

Among the sensible heat storage technologies, only technologies that address intra-day energy demand imbalances are being widely adopted. Examples of this trend can be found in the strong promotion of **smart hot water tanks** and **electric storage heaters**. Furthermore, innovation within this range of TES technologies is focused on developments that allow for inter-seasonal heat storage. This is largely due to the fact that currently there are only a limited number of case studies that have successfully utilised the potential of **underground TES** (e.g. borehole energy storage) or **surface TES** (e.g. pit storage),<sup>153</sup> especially within the context of the urban environment.

Market challenges and business drivers

The main market challenges include

- High upfront costs
- Well established traditional technologies; high competition for new market entrants
- Challenges related to grid integration, and integration with existing heating systems
- Urban planning limitations
- Lack of efficient price signals
- Lack of consumer awareness

Business drivers for heat storage include

- New business models; new partnership opportunities as heat storage becomes a part of the heat network
- Financial incentives; preferential schemes related to utilisation of renewable energy
- Dynamic development of smart grids
- Need for compliance with stringent EU energy efficiency targets
- Benefits resulting from sector coupling (e.g. power to heat solutions)
- Increasing demand for a large scale energy storage (especially inter-seasonal)

Companies and solutions to watch

1. Suntherm (Denmark) – cost effective thermal energy storage solution that utilises the phase change materials
2. Ecotechceram (France) – Modular thermal energy storage solutions that use refractory ceramics produced from inorganic industrial waste.
3. Bilfinger (Germany) – A system that is able to store excess wind and solar energy as heat in the rock-fill and convert it back to electricity when needed by using steam generators.<sup>154</sup>
4. SaltX – Swedish innovation company that has developed and patented a ground breaking technology with which energy can be stored in salt, and subsequently recovered in the form of heat or cold

Integrating solutions

Energy efficiency gains that allow for the reduction of air pollution resulting from energy demand relating to the building management sector can be achieved if innovations are being applied to specific technologies. Ideally, this will also entail the creations of feedback loops between different technologies, with each reinforcing and / or advancing the efficiency of others.

Besides efficiency gains that arising from the integration of different technologies, coupling of different heating solutions often allows us to counteract issues related to the intermittent nature of renewables. Currently, the main barrier blocking a quicker uptake of RES is this very issue, and thus solutions involving supporting technologies have the capacity of not only increasing the stability of the system overall, but through this, to reduce the environmental impact the sector.

Current state and outlook

Stakeholders are already making use of the benefits arising from the still relatively small presence of smart grid systems. Gains derived from systemic integration could however



still be much higher. If further developments are made in the areas of **grid integration and microgeneration**, as well as if new, **multisource heating solutions** are applied on a wider scale as a part of the network, there is enormous upside potential. Further benefits from integration associated with smart grid technologies can be found in real-time heat demand management, and the opportunity to aggregate heat and electricity demand by merging the heat and power networks. This will allow for more efficient grid management, and thus optimisation of resource use by utility operators.

Also worthy of note is the rapid development of digital technologies (for example blockchain), as these address consumer concerns regarding privacy, convenience, etc., which previously hindered the uptake of microgeneration solutions.

*Market challenges and business drivers*

**The main market challenges include**

- High upfront cost
- Lack of consumers’ technological awareness
- Multiple stakeholders; complex level of interoperability between devices is needed

**Business drivers for integrating solutions include**

- Low operation costs
- Optimisation of resource use by utility providers, through for e.g. demand aggregation
- Ability to manage peak load more efficiently and avoid grid imbalances; high consumer demand for instant heat and power provision

**Companies and solutions to watch**

1. Ecovat (the Netherlands) – thermal storage of renewable energy and its integration in a hybrid microgrid, with power-to-heat flexibility services that can be provided to the electric grid

**Heat generation**

**Heating from renewable energy**

Heating has been named as renewable energy’s next frontier by the International Energy Agency. Most of the heat in buildings is currently mostly produced through the burning of fossil fuels, which as we have seen, has been identified as the culprit behind many environmental and health issues. It is perhaps surprising then, that developments in the application of renewable energy in the production of heat have not been nearly as dynamic as in the transportation sector.<sup>155</sup>

**Current state and outlook**

Most recent data shows that renewable energy accounted for 18.6 % of total energy use for heating and cooling in the EU in 2015.<sup>156</sup> However, a further increase of 8.4% (reaching 27% overall) in renewables’ share in heating and cooling is needed in order meet EU energy mix targets by 2030.<sup>157</sup> Thus, the integration of renewable energy as part of our heat source is a field with both a great potential and need for development.

Currently, technologies that allow for the use of **bioenergy** are playing the most significant role in the provision of heat from renewables. However, it is important to assess the sustainability and viability of biomass usage in the life cycle i.e. by providing local supply of good quality resources and implementing low emission biofuels combustion technologies. On the other hand, in coming years, solutions that enable the utilisation of **solar energy for water heating** (although available since the 1980s), are expected to experience a surge in demand. This will especially be the case once improvements such as freeze protection systems and other adjustments for colder regions are made more viable. Similarly, technologies that allow for the use of **deep geothermal energy** use have already reached market maturity, although mostly only in large-scale applications. Further research and innovations are needed to realize the full potential of shallow geothermal resources by individual users.

*Market challenges and business drivers*

**The main market challenges include**

- High upfront costs
- Low consumer awareness
- Lack of technical knowledge and competence
- Space and infrastructural limitations

**Business drivers for heating from renewable resources include**

- Lower operating costs
- Financial incentives; governmental subsidy schemes, grants etc.
- Stringent EU regulations; targets for the use of renewable energy
- Increasing prices of conventional energy

**Companies and solutions to watch**

1. Sunridge (the Netherlands) – orientation-independent, building-integrated solar collector for hot tap water production
2. Energeotek (Sweden) – NxGEO solution allows for highly efficient heat production from geothermal wells

**Micro-algae for energy and clean air**

**The need**

While energy consumption is rapidly growing around the world, we continue to generate power primarily using conventional fuels. In urban areas, this means that air pollution has become both a health hazard and an urgent problem. One possible solution might be to make use of micro-algae in energy production. Micro-algae are widely regarded to have great potential in the biotech industry as their genetic diversity and resilience provide an optimal bio-platform for the production of anything from biofuels to food supplements.

**The solution**

Solaga, a start-up from Germany, is developing a range of microalgae-based products, including a patented technology that enables the production of biogas using Cyanobacteria.<sup>158</sup> By affixing algae growths to a panel (similar to solar panel), the colonies function as a factory, consuming only the energy necessary for staying alive. All the while, the algae creates by-products that are easily and efficiently converted into methane – a process which only uses sun light, CO<sub>2</sub> and a few trace elements.

**Value proposition**

Solaga panels can easily be mounted on any surface with access to sun light and air. The process is designed such that not only are CO<sub>2</sub> and other trace elements removed from the air, but also that quantities methane viable for use in energy generation are produced. The widespread use of cleaner burning methane promises to improve air quality and microclimates in cities, while the resulting green facades will enhance the look and feel of urban environments.

Source: TBB catalogue,2017 edition



## Straw as an efficient, cheap and eco-friendly fuel

### The need

Biomass is the oldest, and one of the most widely used renewable sources of energy. One of the most popular types of biomass is straw, and in Poland, nearly 30 million tons of straw are produced each year (most of which is currently used as feed or livestock barn lining)<sup>159</sup>. With such large quantities of straw being produced, it is estimated that approximately 10-12 million tons, could be used to produce heat, but the challenge remains to further enhance the usability and efficiency of straw-fired biomass boilers. For farmers, rural businesses, and local communities looking for cost-effective and low emission heating systems, efficient straw-fired biomass boilers could offer significant advantages.

### The solution

Bio-Eco-Matic is the first fully automatic straw-fired batch boiler. The boiler has an automatic loading system, as well as a drying and filtration chamber which allows for use of low quality fuels with a moisture content above 40%. The system also offers increased straw combustion efficiency, resulting in greater optimization of both inputs and output. Due to the fact that the heat produced from straw is approximately 10x cheaper than that generated using natural gas, the payback period is estimated not to exceed 5 years, and the overall life of the system is over 20 years. Optimized both in terms of efficiency and low emissions, the system can be fitted additionally with an automatic ash removal apparatus, as well as a heat exchanger cleaning system designed to maximize ease of service. With outputs ranging from 500 KW to 2 MW, Bio-Eco-Matic is an excellent solution for large agricultural farms, rural communities, as well as companies located in rural areas.

### Value proposition

MetalErg provides a low-cost, low-emission, independent, convenient and efficient heating system for a variety of commercial, agricultural and residential applications. It has a modular design which allows the final configuration of the boiler to be tailor made for each customer, taking into account the energy requirements, type of available straw, and space restrictions.

Source: TBB catalogue, 2017 edition

## Combined heat and power stations

It has been realised that high losses from the centralised heat and energy infrastructure need to be addressed, as stakeholders look for solutions that allow us to meet the energy efficiency levels required by new EU regulations. Decentralised solutions such as cogeneration can be viable answers that allow us to improve overall system performance, while minimising air pollution and other negative environmental impacts resulting from heat and power generation. Cogeneration is the simultaneous conversion of a single fuel source into two useful energy products, in this case electrical power and steam/hot water. Effectively, this process makes use of otherwise wasted heat from power generation to meet heating demand.

### Current state and outlook

Although the technology is well-established, and has already reached market maturity, there is even more potential for cogeneration to account for a larger share of heat production. This potential for growth is to be found in expansion into integrated, small-scale generation. Advancements will need to focus on microturbines, stirling engines as well as fuel cells in order for the technology to be viable in terms of cost for the individual consumer.<sup>160</sup>

Europe currently accounts for 11% of the global active CHP capacity,<sup>161</sup> however, several programmes such as Ene.field have been introduced in order to enhance the uptake process, especially of the micro-CHP systems.<sup>162</sup> In this vein, the installation of 1,000 fuel cell micro-CHPs was recently scheduled as part of a pilot scheme. Unfortunately, beyond such trial projects, in most European countries, this technology is still underdeveloped, existing solely at the R&D stage, and applied only on an experimental basis.

Moreover, a great focus within the R&D sector is currently being placed on trigeneration, a more advanced solution which converts the fuel source into three useful end-products: electricity, steam or hot water, and chilled water.

### Market challenges and business drivers

#### The main market challenges include

- High technology and upfront costs; capital intensive
- Unfavourable policies and regulations
- High grid access cost for consumers
- Need for stable heat and electricity demand

#### Business drivers include

- Financial incentives; significant governmental support
- New revenue streams; sales of excess energy and industry specific products
- Growing demand for of stable, uninterrupted electricity and heat supply
- Possible partnerships with utility enterprises
- Shorter time to deploy than needed for the utility company to extend transmission and distribution services
- Ability to integrate renewable resources; meet stringent EU regulations
- Lower operating costs; reduction of distribution costs
- Development of small-scale solutions available for individual consumers

#### Companies and solutions to watch

1. SolidPower (Italy) – innovative micro-CHP systems based on the high temperature fuel cell technology
2. N2telligence (Germany) – HyCogeneration – trigeneration system based on hydrogen fuel cell technology
3. Entrade – turn-key CHP systems for solid biomass with high-temperature reactor



Polygeneration as a local smog countermeasure

The need

More than 80 percent of Europeans living in urban areas breathe air that exceeds pollution norms determined by the World Health Organisation. This creates the necessity to commercialise sustainable energy solutions that improve efficiency and limit the negative impact of energy production on the environment.

The solution

Polygen is a plant designed for the generation of synthetic natural gas (SNG), electricity and heat from alternative fuels such as waste sludge, solid urban waste (MSW) and biomass, which allows local communities reduce air pollution and achieve energy independence. Polygen produces gas through methanation, a unique gasification technology which is based on bubbling fluidized bed gasifier that uses a wide range of residues (cartridge discharge residue – CDR) and sludge) and biomass as fuel and can operate year-round enabling gas surpluses to be transferred to local networks. In addition, it is possible to individually adjust the operating parameters to local supply of raw materials, i.e. wood biomass or municipal waste in order to minimize transport costs. The project is run by a consortium formed of seven European highly specialized companies which are leaders in their areas of business from Poland, France and Spain. According to their estimate, the potential market for this technology is worth approximately €3.24 MLN until 2027.<sup>163</sup>

Value proposition

Polygen Project promotes both environmental sustainability and the development of the local economy in line with a concept of the circular economy. It converts the generated waste into cost-effective energy that can be used to fulfil energy demand in the area.

Heat pumps

As the built environment is responsible for substantial energy consumption in the EU, there is a strong need to establish technologies that allow us to limit primary energy use in the construction sector. In recent years, heat pumps have gained recognition as an efficient way to satisfy demand for heat without putting excessive pressure on the environment. Importantly, heat pumps are a zero-emission heat generating technology which use electricity and renewable energy from either air, water or ground. This in turn decreases fossil fuel energy demand and resulting air pollution.

Current state and outlook

Currently, **ground, ground water and air source heat pumps** are the three most commonly employed technologies. As identified by the European Heat Pump Association, air source heat pumps dominate the market. However, as the commercial and industrial sectors become more interested in the implementation of these heating technologies, the demand for geo- and hydro-thermal heat pumps is increasing.<sup>164</sup>

Vast knowledge of, and well-established technologies surrounding these solutions facilitate deployment of heat pumps in Europe, where the market has been experiencing continuous growth in recent years. A dynamically developing construction sector, coupled with increased demand for renewable energy, and stringent energy efficiency targets led to heat pump market growth. This has translated into a 12% increase in 2016 alone, with a further annual increase of 15% for 2017 predicted by the experts from the EHPA.<sup>165</sup> It is worth understanding though, that innovations

are needed in heat pump control and automatic management, so that they can become fully integrated with smart grids. This will also involve improvements to general design and functionality so as to enable more efficient technology coupling (e.g. with solar thermal system) and infrastructure integration<sup>166</sup>.

Market challenges and business drivers

The main market challenges include

- High installation costs
- Lack of consumer awareness
- High cost of integration in the existing infrastructure

Business drivers for heat pumps include

- Increasing demand for smart heat grids
- Need to comply with EU regulations
- Stringent energy performance standards
- Financial incentives; preferential terms for heating systems that are based on renewables
- Technological advancements leading to falling prices

Companies and solutions to watch

1. Vaillant (Germany) – flexoTherm – multisource heat pump with smart connectivity interface
2. enOware (Germany) – miniaturised sensor to professionally plan geothermal probes for the heat pump industry

Energy recuperation

Energy recuperation in a form of heat recovery allows us to decrease primary energy demand from built infrastructure, and thus to limit the negative externalities related to the heat generation process. Two processes that allow for heat recovery are currently being dynamically developed, namely: **heat recovery ventilation (HRV)**, as well as the **Organic Rankine Cycle (ORC)**.

Current state and outlook

HRV works by facilitating the transfer of heat between outgoing and incoming fresh air within a building, providing efficiency ratings of up to 85%. Such levels have become especially important in light of the ambitious EU targets for building energy performance.<sup>167</sup> As such, it has been predicted that the European Nearly Zero Energy Buildings directive, in coming years, will significantly enhance demand for HRV solutions.

Similarly, technologies that incorporate the Organic Rankine Cycle (ORC) (a heat conversion technology which uses working fluids boiling at much lower temperature than water) are also of key importance to energy recuperation. Their further development is imperative, as these technologies allow us not only to increase the efficiency of the heat recovery process in general, but also enable the incorporation of low temperature heat sources such as geothermal or solar energy. One combination of technologies which serves as a good example for such innovation is the combined ORC-Heat Pump system, which due to its unique set up, has a potential to increase the fuel-to-heat efficiency of heating systems by around 130% to 160%.<sup>168</sup> Another example are ORC-CHP or ORC-Concentrated Solar Power systems, which due to their flexibility, allow for production of not only the high temperatures needed for the production of electricity, but also of the lower temperatures required for district heating purposes.

Market challenges and business drivers

The main market challenges include

- Capital intensive; long term return period
- Lack of awareness; perception of waste-heat generation as a ‘by-product’ rather than profitable opportunity
- Waste heat is of lower quality need for more advanced heat exchangers
- Multiple stakeholders and their lack of know-how



Business drivers for energy recuperation include

- New sources of profit for consumers
- New business models – partnership opportunities between otherwise unnatural partners
- Optimisation of resources
- Increased efficiency in use of renewables; share will increase in coming years due to stringent EU regulations

Companies and solutions to watch

1. Climeon (Sweden) – low temperature heat recovery technologies
2. Ventive (UK) – heat recovery system from naturally driven airflows
3. Turboden (It) – Organic Rankine Cycle (ORC) systems



Recovering waste energy makes your heating even more efficient

The need

With conventional heating systems, one of the primary factors that affects the unit's efficiency and fuel consumption is the temperature at which combustion occurs. Inefficient systems, particularly those which burn at lower temperatures, are those which release greater amounts of unused energy with their waste output. Other than the demand for more efficient systems created by rising fuel prices, new environmental requirements and legislation are driving the market forward by imposing measurable benchmarks in terms of acceptable energy loss.

The solution

Energy Turbo FGR<sup>169</sup> recovers waste energy by condensing the flue gas, cooling it, and then extracting the heat so as to put it back into the system. The patent pending solution is optimized for 100-1,000kW heating systems, and can increase thermal efficiency by up to 20%. One of its advantages is that it is offered either as an integrated or stand-alone unit, and can easily be used for retrofitting existing systems (regardless of fuel), as long as the system generates hot humid smoke (flue gas).

Value proposition

By recovering waste energy, Energy Turbo FGR® enables a reduction in the consumption of fuel associated with heat generation, and mitigates the tougher environmental requirements being imposed across Europe. It also benefits from a short payback period, and significantly reduces soot particles as well as emissions of harmful gases (CO<sub>x</sub>, NO<sub>x</sub>, SO<sub>x</sub> by almost 90%). The Energy Turbo fits very well into the dominant configuration of decentralized heating around Europe, and can easily be used to upgrade existing heating systems.

Source: TBB catalogue,2017 edition

Revolutionizing Thermal Energy Storage

The need

It is estimated that about 20-50% of the energy used in industrial processes is discharged as waste heat. Waste heat generally has lower utility than that originally generated due to its lower temperature (usually temperatures below 220 °C). Although this by-product cannot be reused in the same industrial process, it is ideal for space heating, water heating or preheating in different technological processes. It is possible to transfer the heat via a heat pipeline, however it is economically unfeasible below the amount of approximately 10MWH/day of transferred energy.

The solution

Mobile heat storage (MHS) is an innovative technological solution developed by a Polish start-up Enetech. The system itself is effectively a special container used for the storage and transportation of heat over short distances (up to 30 km). The container makes use of a phase changing material, or PCM (usually different types of paraffin) that has a high thermal conductivity, so as to retain heat. What is more is that it leverages the latent heat of fusion, and offers approximately 6 times more efficiency than a regular water boiler (up to 172 kWh/m^3). As the temperature of the stored heat does not exceed 120 degrees, the contents are perfectly suited to central heating applications. Furthermore, the heat container is transported to the final recipient and left there for the time of its discharge, during which time, a second container is charged in the loading station. The return on investment (including payback time) is case specific, and depends on a wide range of factors. It can be assumed that under the best possible circumstances, return on investment is estimated to be around 6 years without government subsidies.

Value proposition

This solution enables the transfer of thermal energy at constant temperatures without the need for investment in expensive heat pipelines. It provides an opportunity for small scale CHP plants that can separate heat generation from electricity generation, as well as for biogas plants which usually treat heat as a byproduct. In both instances, this technology has the potential to attract new off-grid customers, while at the client end, the recipient reduces the per kWh cost of heat while at the same time reducing CO<sub>2</sub> emissions.

Source: TBB catalogue,2017 edition

4<sup>th</sup> and 5<sup>th</sup> generation district heating

Although the stakeholder community has already recognised the significant role of district heating in the process of increasing the energy efficiency of the overall system, technologies that mitigate the negative impacts of heating on the environment need to be further developed. 4<sup>th</sup> and 5<sup>th</sup> generation district heating, through the integration of renewable resources, such as low-temperature heat production units, reduce grid losses as well as leverage potential synergies arising from a combination of different technologies.

Current state and outlook

Extensive R&D activities currently focus on 4<sup>th</sup> and 5<sup>th</sup> generation district heating, i.e. **low temperature and ultra-low temperature heating** networks. These work by exploiting the untapped potential of low-grade heat sources (predominantly renewables). New generations of generation have not only the potential to reduce network heat loss by as much as 75%, but also to increase the efficiency of heat production itself.<sup>170</sup> Technologies that enable us to upgrade to the 4<sup>th</sup> generation of district heating have already been implemented by several cities such as Lystrup (Denmark) and Chalvey (UK). However, it should be noted that it has been done mostly on a trial basis.<sup>171</sup>

Interestingly, systems that can exploit neutral (15–20°C) temperature levels for heating and cooling purposes are currently being investigated. The set-up of such 5<sup>th</sup> generation district heating systems offer the promise of further reductions in heat loss, but above all, they make possible increased efficiency gains through both recovery and recycling of the networks’ ultra-low temperature waste heat<sup>172</sup>.

*Market challenges and business drivers*

**The main market challenges include**

- Lack of consumer awareness; high demand for instant provision of heat
- High integration costs with existing infrastructure; current heating systems may not be equipped appropriately to accommodate low temperature district heating
- Restricted space heating capacity in the existing infrastructure
- Consumer health and safety concerns (Legionella thrives in low heat environments)

**Business drivers for 4<sup>th</sup> and 5<sup>th</sup> Generation District Heating include**

- Compliance with energy efficiency targets for buildings and other environmental and energy related norms
- Possibility of new partnerships (e.g. data centres and district heating operators)
- Resource optimisation due to the reduction of lost capacity during heat transfer
- Integral component of smart heat grids, for which demand is increasing
- Ability to integrate intermittent renewables
- Lower infrastructure costs; ability to use plastic piping which is cheaper than currently used metal infrastructure

**Companies and solutions to watch**

1. Rehau (UK) – Thermally Activated Building Structure – incorporation of pipework into concrete for low temperature heating and cooling purposes
2. Airedale (UK) – prototype of district heating recycling scheme; waste heat recycling from data centres

**Decentralised heat generation**

The current model of highly centralised heat generation may be unable to meet the increasing challenges resulting from more stringent environmental regulations and tighter energy efficiency targets. Although centralised solutions have for a long time been more economically attractive, recent improvements in the efficiency of small scale heat generation technologies (and resulting decrease in their costs), have resulted in an increase in demand for new, consumer



oriented heat generation models. Decentralised heat generation not only allows for demand driven responsiveness, but also allows for a greater share for renewables in the heat generation processes. This in turn limits the predominantly fossil fuel based demand for primary energy on the part of centralised generation, and thus addresses concerns related to air pollution which arise from conventional combustion.

**Current state and outlook**

In recent years, solutions that enable household-level heat generation (**microgeneration**) have gained momentum. Currently, small-scale technologies such as solar-thermal hot water systems, heat pumps, high-efficiency low-emission catalytic biomass stoves and boilers, as well as combined heat and power units can provide the amount of heat needed to satisfy the consumer’s demand while reducing the domestic air pollution emissions.

All of the aforementioned technologies are well established, and it is well understood that energy efficiency as well as resulting air pollution savings from their implementation can be as high as 60%.<sup>173</sup> It is slightly confounding then, that their uptake has been relatively slow, and this is perhaps because successful implementation is highly dependent on public support – a reality which is only now becoming understood. As a result, numerous authorities are actively trying to increase share of decentralised technologies through both legislative and informative campaigns. In one widely publicized example, the city of London has pledged that 25% of city’s energy needs will be covered through decentralised solutions such as local heat networks.<sup>174</sup>

*Market challenges and business drivers*

**The main market challenges include**

- Limited grid capacity; high costs of integration with existing infrastructure
- High consumer demand for a stable energy supply; intermittent nature of decentralised heat generation is a main factor for consumer apprehension
- Need for cooperation between different regulatory frameworks
- Lack of consumer awareness
- Restrictive planning regulations
- Lack of skilled workforce
- High upfront investment costs

**Business drivers for Decentralised heat generation include**

- Increasing demand for smart heat grids
- Quick system response time; ability to meet ad hoc spikes in heat demand
- New business models
- Different stakeholder groups and engagement – numerous partnership opportunities with private bodies, as well as utility providers
- Compliance with environmental regulations
- Optimisation of resources – ability to reduce the risk of negative prices triggered by low demand
- Financial incentives; available government subsidies and grant schemes

**Companies and solutions to watch**

1. Meva Energy (Sweden) – Decentralised biomass cogeneration with 2nd generation biomass
2. Dandelion (USA) – geothermal installation services for individual customers





# Non-technological enablers and demand for innovative solutions

The objective of this section is to provide an overview of the non-technological factors that shape the demand for innovative solutions, as well as absorptive capacity. In line with the report's main objective, the focus is divided between market and non-market drivers, as well as the barriers which ultimately determine both the possible environmental impact, and the expected investment attractiveness.



# Education and information in relation to social change

As has likely become evident through the course of the previous sections, a plethora of both technological and developmental solutions are available to us in the quest to reduce producer, user, and systemic inefficiency. The flip side to this is the necessity to foster an environment amenable to the continued development and implementation of these innovative solutions. Some have the capacity to be disruptive, but others will require more controlled conditions to thrive within existing markets. From this, we can easily see how the tide of both rising environmental awareness and social participation creates a set of opportunities and challenges for innovative investments.

We have also seen how both government and citizenry have equal share in the success or failure of new environmental policies and technologies. This means that policies have to transparently reflect the overarching priorities of society, and that individuals have to be committed to change.

Interestingly, it has been shown that there is a direct correlation between a higher level of education, and concern about the environment.<sup>175</sup> Relevant to this study is that education also seems to directly affect both consumption and behavioural patterns vis-à-vis environmental issues. According to the OECD, there is a correlation between level of education, and individual energy / water use (as education rises, consumption decreases), as well as between education and active involvement in environmental issues.<sup>176,177</sup> Following from this, it is safe to assume that the more people know about the issue, the more likely they are to be amenable to the adoption of new technologies and policies.

We are then faced with the issue of how to inform the population about environmental issues – in this case, air pollution. Basically, there are two main ways to educate society about air quality – to conduct environmental awareness campaigns in the media, or to influence behavioural change. Taking a top down approach, this might entail the government, the media and experts with social, political or economic authority being responsible for a cultural shift. This might be accomplished by applying creative insights, or by producing projects that improve public awareness about the challenges and risks associated with air pollution. Alternatively, a coordinated (perhaps more coercive) volley of legislation, if properly crafted, might also forcibly change consumer behaviour, but it should be backed by comprehensive and transparent assessment of total costs and benefits.

## Smogathon – a global competition for air pollution-fighting innovations

Cracow has been facing a problem of air pollution for years, however for years no one seemed really concerned about it. The more citizens were aware, the more actions were taken to make a change, however it just wasn't enough. One short bike ride during a smog episode, became a trigger, that started soon to be the biggest technological initiative which fights air pollution – Smogathon. The whole initiative started as a bottom up movement that encouraged young poles to create anti-smog solutions and innovation during a episode became – only 5 weeks of preparation brought over 300 people that were involved into this event – which was a clear sign of people having ideas and wanting to change something. Local initiative quickly become international, when media started noticing actual activities and implementations from first movement. It was basically a proof Smogathon's main concept – it's possible to fight air pollution with innovation. Second edition got interest of over 60 projects from 3 continents. Moreover,

it brought an effect of rising awareness, especially among an active group of young poles, who wanted to do something about air pollution and were tired of waiting for top-down actions. As a community started to grow around Smogathon, it became something more – an organisation that provides new opportunities and possibilities for development of projects from various parts of the world. Organisation of semi-finals in 5 countries, growing network of world's class experts and coverage of international media helped to reach over 120 applications from 6 continents in 2017 edition. Alumni's growing number of implementations proves that innovation and technology could help to solve one of the world's most emerging problems. Smogathon has evolved from local hackathon to global initiative, but main mission has not change – it helps to fight air pollution with innovation and brings implementations of various projects all around the globe. Now, globally.

Maciej Ryś *Leader of the Smogathon*

Assuming a more bottom-up perspective, common data access based on reliable evidence can be seen as a necessary factor in engraining air quality issues in a society's zeitgeist. Mobile applications such as Airly,<sup>178</sup> CleanSpace,<sup>179</sup> Smart Citizen Kit,<sup>180</sup> and Air Quality Egg<sup>181</sup> all serve to increase the availability of precise, localized data. The subtext is that environmental monitoring will hopefully induce social action, or even calls for policy change based on a better understanding of the causes, effects, and possible solutions to the issue of air pollution.

## Check the air quality in your neighbourhood using the Airly app

By building a network of air quality sensors placed across entire cities, the application aims at providing people with comprehensive information about the quality of the air. Sensors are placed on buildings with a maximum distance of 1 km from one another to ensure proper coverage, as well as precise measurements. They collect data about concentrations of particulate matter PM<sub>2.5</sub> and PM<sub>10</sub>, temperature, humidity and air pressure, all of which is then processed. The app then generates an intelligible report for the user. Sensors' installation is very easy, and it only requires an active wi-fi connection, power

supply, and correct configuration. The main advantage of the application is that it uses real-time data to create air quality forecasts, which then help to identify the sources of air pollution within a given city. This data can then be leverage so as to target the underlying causes more effectively. Airly also provides collected data to other app developers, who might want to use it in their own weather forecasts.

Source: <https://airly.eu/en/>

As was previously mentioned though, awareness is but one component in any conceivable solution, there will always be at least some apathetic or unattuned segments of society, and it is here that governmental action might prove itself imperative. Such measures need not necessarily be as affirmative as taxation or legal limitation – gestures as simple as encouraging public transport through investment and public policy, or introducing smog announcements in public places have proven to go a long way.<sup>182,183</sup>

More passive policy instruments have proven quite effective in laying groundwork for more restrictive ones. For instance, when public transport is attractive enough to draw in regular car drivers, cities have moved on to congestion charges, as introduced in London, Singapore and Stockholm.<sup>184</sup> Similarly, in Nottingham City Council a type of charging scheme called the Workplace Parking Levy (WPL) has begun charging employers who provide parking to their employees a flat fee of £379 per parking spot annually. Revenues from the WPL in the first of three years amounted to over £25 million, and covered the costs of expanding the city's tram system, renovating the main railway station and paid for 45 electric buses.<sup>185</sup> Although these schemes do not seem remarkable in and of themselves, it is interesting to consider that they effectively constitute examples of socially accepted environmental taxes – a concept which certainly would not have been so palatable if not both gradually worked up to through public awareness, and carefully considered in implementation.

Slightly more forceful are policies which directly address behavioural change, such as the ban on diesel cars in place in Athens, Brussels, Copenhagen, Hamburg, and Oslo. The last city plans to permanently ban all diesel vehicles in the city by 2019, and as such, is investing in public transport by replacing roads with bike lanes, and has accompanied this with a public service announcement campaign.<sup>186</sup>

A slightly softer approach, although in a similar vein, can be found in the UK, where the Department for Transport has estimated that 56% of all car trips are for a distance of less than 5 miles. It has been further identified that by providing both facilities and safe solutions for cyclists, many could be persuaded to switch from cars to bikes for shorter journeys. It is hoped that these emissions-related initiatives might interlock with existing 'healthy life-style' campaigns, thus fostering a dynamic cycling culture.

Ultimately, it would seem that the strategies adopted by EU countries appear to be working. Other than the aforementioned successes, a study by the European Commission reported that a full 75% of respondents believe that their quality of life is impacted by the state of the natural environment, and 77% think that environmental problems have a direct bearing on their everyday lives. Furthermore, 77% see environmental action undertaken by large companies and industry as insufficient, and this number only drops to 70% in relation to national governments.<sup>187</sup> From these figures, it would appear that generally, Europeans are receptive to more affirmative action with regards to the environment.

The role of social media and the dangers of information in an information age

Thus far, it is probably looking as if we have a clear course of action – politicians and media tread lightly around the issue until general education and awareness allow for bold actions, which might even ultimately be perceived as organic policy decisions. The concept is to first capture the public imagination, and then leverage what sociologist Emile Durkheim referred to as “collective effervescence” (a sameness of thought between individuals of a given social unit) so as to implement tangible changes in the way that society and economy operate. Unfortunately, the power of the collective conscience is a double edged sword, and the path from knowledge to action is not as clear as it might at first seem.

One of the most volatile forums for societal change is **social media** – it at once has the ability to harness the power of whole demographics, and also to spread fear and misinformation – a phenomenon sometimes referred to as “**fake news**”. As Durkheim posits, collective effervescence – the incommunicable solidarity of communities regarding certain issues or beliefs – can at times be constructive, and at others volatile, much like a mob. The ability of social media to connect the individual on a seemingly personal level to other people or beliefs means that it can work in much the same way. If the right chords are struck, even implausible information can be readily accepted as true for reasons of self-validation.

Dangerously, this can have social and economic ramifications outside of cyberspace, with companies in the fields of nuclear, wind, biomass, biogas, and even solar energy generation seeing virtual slander lead to material loss.

Oftentimes, it requires an arduous, lengthy and costly social dialogue to correct unfounded beliefs – a reality which has already set some renewable energy sources back by years. Private industry, with a keen eye to the bottom line, has identified this new type of risk, and has now begun to factor in the Not In My Back Yard, or NIMBY effect when doing cost or risk analysis. It is even conceivable, depending on how it is weighted in the valuation, that reputational risk to a firm due to the NIMBY effect might even prevent the pursuit of a project all together.

Economic and regulatory determinants of innovation

Back in Chapter 2, we introduced the problem of negative externalities associated with air pollution as well as smog, and though the issues are themselves a central motif, this report also focuses on innovation. The term ‘innovation’ has a broad definition, and encompasses a wide range of activities. In addition to R&D, it includes organisational changes, training, testing, marketing, and design. As innovation is widely considered to have positive effects on society and the economy beyond those received by the innovating entities, it has positive externalities associated with it.

Not in My Back Yard (NIMBY)

Is a social attitude that can be defined as a sign of protest on the part of inhabitants against an investment (e.g. a power plant or a transmission grid) if it will be built close to where they live. In some cases it is a rational behaviour on the part individuals who own real estate, businesses or highly value local landscape. Some investments in heating or transport inevitably create negative externalities for the immediate neighbourhood, despite increasing the overall social welfare.

Fundamentally, it is a problem of a perceived imbalance in the benefits and costs of a given project. What is more is that local communities oftentimes feel that they have a strong economic argument for demanding compensation from those who will be better-off as a result of investment. In light of this perception, broader public interest, including those of the nation (such as energy security), become subordinated to more individual wants and needs.

Chapter 5 of the report discusses the challenges associated with the selected technological solutions in transport and heating. The analysis presented many common issues for innovating and diffusing innovation in heating and transport:

- First of all, many technological solutions in heating and transport require investment in infrastructure, a process which tends to have **very high upfront costs** associated with it. For example, in the case of electric vehicles, UBS estimates that the required investment in charging infrastructure in Europe will be around \$14 BLN.<sup>188</sup> In this area, government grants and subsidies to fund the development and maintenance of infrastructure can reduce the overall cost, and thus encourage more supply. Additionally, infrastructure enables the further diffusion of related technologies that depend on it.
- On top of this, many of the areas where innovation is needed **intersect with governmental responsibilities**. For example, public transport and traffic management are under the auspices of city authorities, while heating grid and heat generation are managed by large companies. The latter tend to be state-owned or conservatively minded, creating a barrier for developing and diffusing innovative solutions. National and regional governments can help the situation by encouraging the exchange of experience and the transfer of knowledge, as well as providing financial support to test and implement solutions.
- Furthermore, a **lack of awareness and the underdeveloped technological capabilities** of customers can predetermine their purchasing decisions, preventing them from using renewable sources in heating or alternative fuels in transport. Awareness and increased technological understanding could play a paramount role in helping diffuse innovation. There are studies which have attempted to measure the role of awareness in technological diffusion, most of which posited encouraging results. For example, a study on electric vehicles in Europe found that the



Ultra-Low Carbon Vehicle campaign in the United Kingdom increased the willingness to pay for the less environmentally damaging vehicle by 51 to 74 per cent.<sup>189</sup> Additionally, especially in transportation, diffusion of innovation can have **network effects**, with more users increasing the value of the product to others. Each actor plays a different role in the innovation diffusion process, and thus the path to acceptance is subject to socio-economic characteristics, personality, and communication behaviours.

- Finally, even though economic studies have been inconclusive on the relationship between company size and innovation, **small and medium enterprises can be inherently constrained** in their activities. This is primarily due to the shortage of financing and a highly skilled workforce, and can lead to a lower innovation intensity at SMEs than larger companies. Yet, smaller firms may have some inherent advantages in producing more “radical” changes to flexibility in products and technologies, but in order to exercise this ability, the SMEs need to operate in a supportive environment.

In general, the government can play a key role in creating a fertile environment for innovation, by investing in the foundations for innovation and by helping overcome barriers. The aforementioned policy instruments need to fit a broader enabling framework, including policies which create skilled workers, a sound business environment, and strong governance. The OECD provided guidelines for governments on how to design the right regulatory environment to strengthen innovation and make it supportive of inclusive and green growth (see the box).

Lastly, besides supporting innovation, governments need to find smart ways to prevent environmental destruction. Studies show that environmental regulations continue to be primarily of the “command and control” type, imposing performance standards across a product or an industry.<sup>190</sup> While such regulations are appealing in their simplicity, they tend to discourage the application of innovative solutions by limiting the ability of companies to develop creative approaches, and by diverting funds from research and development activities. In the environmental sector (including smog prevention), technology-driving approaches are needed, which could include the continuous updating of standards, surveillance of old technologies, or emphasis on preventive standards for new and existing sources of pollution.

**The OECD did an extensive study of Innovation Strategy in 2015, and argued that in order to foster an environment that supports innovation governments need to build:**

- A skilled workforce that can generate knowledge to be used so as to implement innovation. Policies in this area need to help create an environment that enables individuals to acquire the appropriate skills and use them optimally. Best practices include incentives for organisations and institutions to improve the quality and relevance of their training, greater incentives to pursue careers in academic research, and the removal of barriers to women participating in science and business.  
- A sound business environment that encourages investment in technology and in knowledge-based capital. This includes a sound macroeconomic policy, a competitive environment, as well as well-functioning product and labour markets. Additionally, it's important to ensure that international value chains are supported by trade, investment and regulatory infrastructure.  
- A strong and efficient system for knowledge creation and diffusion throughout society. A range of mechanisms might

include the promotion of research excellence, international scientific cooperation, and policies which increase access to publically funded research results.  
- Policies that encourage innovation and entrepreneurial activity through direct funding (such as grants, loans, or equity funding), or indirect sponsorship (such as tax incentives to tackle barriers to innovation). On top of all of this, it must be noted that educated and engaged customers are increasingly important for innovation to be able to properly root itself.  
- A strong focus on governance and implementation in the eye of both increasing globalisation and regionalisation by aligning policy instruments and actions across ministries, agencies, and cross border governance. Governance, implementation and trust in government action play a great role in ensuring that policies for innovation achieve the desired results.

Demand for innovation in transport and heating – specific business drivers and barriers related to households, business and the public sector



Having now seen what challenges, technologies, and strategies are available in the war on pollution, it is worth turning to the specific market realities which will shape targeted solutions with regards to the feasible implementation of them. This will entail an identification of specific demographics and areas where the application of the reviewed material will not only have the most disruptive effects, but also where it can be most effectively utilised.

Among many long-term trends affecting incumbent business models, arguably **the most important is gradual increase of competition with market or quasi-market prices which replace traditional monopolies**. Some areas that still might be regarded as a public good (like motorways, bridges, tunnels and main roads) are often subject to tolls or other economic instruments which aim to charge final users.

**More competition in transport and energy empowers the end user**

In the past, the energy and transport sectors were completely dominated by integrated monopolies, which exploited large economies of scale. In addition, traditional utilities tended often to be the strongholds of influential labour unions and other stakeholders interested in preserving status quo. Since the 1980s, enormous technological shifts, as well as deregulation accompanied by market liberalization have served to dislodge a dependence on old models in many fields including (but not limited to): aeronautics, railways, road transport, and the energy sector. Now consumers can make use of contracted, privately operated car transport in a minute using a smartphone, or make their residence less reliant on on the electrical grid,

thus optimizing their energy bills with use of a smart boiler. The potential impact of the Internet of Things (IoT), big data, and machine learning is still far from over, which means that in future, we can expect even more efficient and competitive markets within the contexts of the transport and energy sectors. However, education, social awareness, and proper regulation are essential for making this happen efficiently - addressing the problems of excessive transaction costs, externalities, and underlying risk. Other industries such as insurance might also foster a spillover of innovation and resulting impact, adjusting incumbent business models to technological breakthroughs like autonomous vehicles.

**Transportation in urban areas**

**Households**

*Users and owners of (diesel/petrol) cars*

**Social awareness regarding environmental protection, and the recognition of its value is increasing, and as a result, instituting a shift to greater usage of environmentally friendly public transport is now possible.** As was discussed in a previous section, car sharing schemes can contribute to significant reductions in particulate matter and other air pollutants. Running parallel to these trends, there is increased public acceptance of autonomous vehicles, as well as a growing demand for personalised services – trends which are mirrored by decreased costs in underlying technologies.

All of these positive trends having been observed, there remains a general lack of awareness as well as technical knowledge regarding new applications of technological advancements, and this may serve to hinder the wider acceptance of alternative transport solutions. Moreover, a backlash

arising from social norms is counteracting a major paradigm shift, as cars are considered symbols of status, and mainstream ‘driving culture’ continues to value absolute human control of the vehicle as central to its identity.

**In some countries, car-free lifestyles are encouraged through legislation, pricing strategies and taxation schemes based on the externalities.** Policy measures targeting mobility and public transport are generally considered good indicators of commitment to urban sustainability, and the coherence between initiatives serves as a good indicator of where a city stands on the spectrum of sustainability.<sup>191</sup> The European Commission has even laid out the requisite characteristics in a statement which posits that “an agenda for a socially fair transition towards clean, competitive and connected mobility for all” should be the overarching goal of mobility solutions.<sup>192</sup>

In the document in which the aforementioned statement was made, investment needs and associated measures are also addressed. This includes the tolling of roads so as to decisively affect current behaviours. It also refers to the Investment Plan for Europe, which is expected to generate new investments to the tune of 194 billion Euros in EU Member States.<sup>193</sup> To support the shift from conventional cars to alternative modes of transport (such as electric vehicles or public transport), it has been identified that increasing the awareness surrounding personal mobility needs, and an accompanying paradigm shift away from car ownership are essential.<sup>194,195,196,197,198</sup>

*Residents of urban areas and those employed in transport (and related) services*

As the opportunity cost decreases, adopting innovative alternatives is becoming more economically viable. Technology presents an opportunity for safer and more environmentally friendly transportation, both by decreasing the probability of accidents (autonomous driving), and by reducing congestion (optimized routes). **This will inevitably mean that some positions will disappear, and that large segments of this demographic will require retraining** – one field that electromobility will help expand is that of power supply management.

As can be imagined, there is likely to be a degree of consternation regarding the automation of professions, and perhaps even societal pushback. What is more is that lack of consumer understanding and awareness may hinder the rapid implementation of technical innovations. Again, privacy and security issues should be top of mind.<sup>199,200,201,202,203</sup>

*The elderly and disabled*

**Two groups that will benefit who will benefit most from electromobility and associated automation are the elderly, and those with disabilities.** In this market segment, individual mobility is highly restricted, and as such, there is the potential for significant improvements in quality of life through the introduction of new technologies. For instance, self-driving cars may increase personal independence, and even serve to enhance experiences relating to medical assistance.<sup>204,205</sup>

One challenge which presents itself is that the adoption of innovative technologies may be slower due to lower consumer technological familiarity and awareness. **The ‘digital divide,’ meaning the age-correlated difference in the level of access and skills needed for using digital technologies, may be considered as a factor which risks excluding the elderly – a concerning issue considering the aging European population.**<sup>206</sup> This is a growing interest group, with potentially significant influence on policy-making, meaning that their enfranchisement is necessary.

Another consideration is that with increased implementation of technology within the context of mobility, **a growing circle of users may present the new issue of cybersecurity to become more pronounced.** As one might anticipate, the system will require data sharing in order to operate effectively. As a result, ensuring the adequate introduction of the new security solutions will be very important, as disruptive innovation may result in new social disparities by virtue of data availability.<sup>207,208,209</sup>

**Business sector**

*Infrastructure managers & providers (transport)*



**Transport innovation is both increasing the road safety, and lowering costs relating to accidents, while simultaneously providing better asset management and resource deployment.** Moreover, with the growing demand for, and availability of smart city concepts, innovations in transportation have the potential to create valuable economic benefits. One thing that managers and providers will have to consider are changes in the user circle – both volume and demographics of end users are likely to change along with societal shifts and greater acceptance of communal transport.

Another consideration for both managers and suppliers will be the infrastructural necessities of alternative fuels. Other than physical necessities, **interoperability will be required so as to ensure widespread use. Last mile solutions in particular will require greater cooperation between infrastructure managers and regulators,** with current innovations and experiments being both spatially limited, and lacking sufficient policy support. With greater cooperation, it is hoped that we can achieve integration with existing infrastructure – a crucial factor, as last mile solutions cannot be considered self-sufficient components of the transportation mix.

From this, it is not difficult to see how innovations are posing complex organisational challenges, and that infrastructure managers as well as providers will have to overcome issues which did not previously factor into how societies get around.<sup>210,211,212,213,214,215,216</sup> Bearing this in mind, market or government dysfunction may be seen as potential barriers, with these two agents converging in the case of state-owned enterprises.

*Construction*

**Automation allows for capacity growth by eliminating repetitive or manual processes, and freeing up labour to dedicate to more specialized, or complex ones.** There are a number of factors which encourage automation, among them an aging and shrinking workforce, efficiency concerns, and productivity considerations, with these drivers offset by economic restraints. This trend in innovation should translate into fewer injuries, less overhead, and greater built output.

Having these positive benefits in mind, the construction industry is both competitive and low margin, meaning that automation is a doubled-edged sword. Innovation becomes both necessary to remain competitive, but also a burden in terms of allocating capital which could have otherwise been deployed to increasing the scale of operations.<sup>217</sup> This is perhaps why, in general, the construction industry has been relatively conservative regarding innovation. Effectively, the introduction and dispersion of new technologies will depend largely on the legal and regulatory support they obtain.

**The construction industry is highly regulated, involving several authorities, and as a result, legislation has the potential to drive change. Of note at this point is that the transportation needs of this sector contribute disproportionately to ambient pollution.** Here, prefabricated or modularized components have the potential to affect positive change by reducing the volume of what is being moved, but these methods are currently underrepresented.<sup>218</sup>

*Fuel (petroleum, gas, and alternative) producers*

As we have seen, a combination of environmental, social, and legislative realities has begun to foster an environment amenable to cleaner fuel solutions. Moves toward alternative energies and commuting strategies have already begun to force fundamental changes in the ways in which we use energy (be it combustion, heat, or electricity). These shifts have in turn simultaneously opened new markets and made others increasingly redundant – a situation which has led to fierce competition within the new energy landscape.

With any change comes a differing narrative or vision, and this is currently the case, as we already see push back from powerful oil and gas companies. This has led to an **emphasis on challenges including ensure supply, scarcity of some key elements, and the distortive effect of alternative fuels on access to mobility.**<sup>219,220,221,222</sup> This has in turn led to alternative technology developers



urging fuel producers to engage more openly with secondary and tertiary infrastructure providers as well as consumers. The hope is that synthesis can be achieved as we move toward more integrated energy production and consumption systems.

*Private urban transport companies (carriers)*

As is the case with other stakeholders, automation and the introduction of intelligent services promise to bring big change to this sector, offering safer transport, and a reduced cost of accidents. **In the competitive market of private urban transport companies, traffic optimization, based on real time data and its analysis, can help improve customer satisfaction through optimal journey planning and communication.** These innovations will simultaneously increase the efficiency of traffic flows, thereby reducing air pollution and road usage. Data analytics also provide opportunity for better tailored products and services.<sup>223,224</sup>

**Financing of innovative fleet is a significant barrier that private (but also public) urban transport companies have yet to overcome.** This means that, as in the case of construction firms, transport companies will likely usually slow to respond to change, due to capital concerns.<sup>225,226,227,228</sup>

*Other industries*

Ultimately, all sectors of the economy will be affected by the technologies which promise to bring environmental change. Some fields, such as the automotive industry are very interested in breaking into new markets and product ranges, and have pursued new technologies with inspiring strategies.<sup>229</sup>

Others have not, for a variety of reasons, whether they be economic, systemic or intrinsic. One criticism often leveled against such stakeholders is that there is no shared sense of urgency, meaning that some avenues of innovation remain stymied in the early phases of development.<sup>230</sup>

With all industries facing the same challenges and rapid pace of technical change, it is imperative that we see intra-sector cooperation. Sometimes this might entail initiating R&D, and in other cases, such as the insurance industry, new understanding will help redefine basic concepts such as liability.<sup>231,232</sup>

**Public sector**

*Central governments and agencies*

Thus far, **compliance with EU regulations has been the main driver for central governments to implement measures supporting the elimination or decrease carbon-intensive lifestyles.** This has proven effective, as joint efforts achieve greater impact due to synergetic effects. For instance, emission standards supports not only climate and clean air objectives, but also serve to improve transportation logistics, and increase energy security.<sup>233,234</sup>

This being said, central governments also have to work in close cooperation with both the business sector, and other public authorities in order to make sustainable development work on a systemic level. Political support and long-term consistency are key to the successful implementation of innovative solutions, and with any support also having to fall in line with a coherent national vision. **Further challenges result from ensuring interoperability on an international level,** and as such, cooperation between European countries is absolutely necessary.<sup>235,236</sup>

*Regional and local governments*

In order to achieve viable multi-modal transport solutions, the implementation of e-mobility and innovative technologies are crucial. Adoption of technical improvements (adaptive traffic lights, variable speed limits, real time data collection) may help in overcoming traffic problems resulting from externalities. Improved traffic flow promises to increase local quality of life, and also facilitate both commerce and communication. In order to ensure EU compliance, the role of local authorities are critical as national bodies will have to delegate some oversight.<sup>237,238</sup>

This being said, **the implementation of large transportation policy frameworks may potentially burden local administrations, especially as they may not have sufficient administrative capacity** in place to meet the rapid pace of change. Ultimately, these barriers may prove more difficult to overcome than the technological ones, as we see certain political cycles counteracting effective long-term decision-making and project management. Moreover, **strong inter- and intra-regional coordination is needed to ensure that local initiatives are interoperable on both regional and national levels.**

As we have seen with other stakeholders, data protection and privacy will be a key issue, as solutions may require the increased use of personal data, meaning that public acceptance and support will be essential.<sup>239,240,241,242</sup>

*Public urban transport companies (carriers)*

**Increased availability and performance of data analytics provide a great opportunity to better understand the public transport model, and allow for more direct communication between users and service providers.** This is good news, as past studies have consistently shown that customer satisfaction highly depends on the efficiency of communication, and that passengers are more accepting of issues if they are kept informed.

Based on travel data made available through new technologies such as smartcards, public urban transport infrastructure and service can also be optimized. These insights may help in discovering new opportunities by monitoring travel patterns, further encouraging the use of public transport or transit services over driving.<sup>243,244,245</sup>

Other than the obvious hurdles surrounding getting people accustomed to new technologies, effective cooperation between stakeholders has the potential to be a sticking point for new technologies in this space. Thus, a careful consideration of the administrative and legal environments will be necessary for not only providing a safety net for users, but also properly organizing existing administrative infrastructure. Ultimately, the success of transport innovations will highly depend on local cultural background and practices, thus societal conditioning will be necessary.<sup>246,247,248,249</sup>

*Other publically funded institutions*

Seeing as how mobility accounts for a considerable portion of average European household spending, it is hoped that innovations will allow for the freeing up of more disposable income to put back into economies and public coffers. In addition, reduced pollution will lessen the burden of related issues ranging from health care to municipal cleaning on administrative infrastructure. This all means more capacity in terms of government budgets, be they local or national.

New navigation and traffic management technologies also have the potential support law enforcement, fire and EMT services. Improved data analytics may help in identifying and prioritising emergencies more effectively, thus contributing to more efficient staff management.<sup>250,251,252</sup>

Again, cooperation between entities presents itself as an obvious barrier to the effective adoption of new technologies. Additionally, with growing electronic infrastructure, demand for rare earth metals, among other scarce resources, may take an unpredictable environmental toll on a global level, and perhaps even foster conflict.<sup>253</sup>

**Heating in urban areas**

**Households**

*People living in detached homes*

It seems clear that *energy efficient construction will improve the value of a home*, while (depending on location), nearly flat utility bills can be realized (thanks to e.g. solar energy), thereby further incentivising buyers.<sup>209</sup> **If market trends continue, houses will become less reliant on public utility**

**systems.** With the lifespans of home integrated generation systems such as solar panels reaching 30 years, heating costs can be lowered substantially, with the upfront cost being dispersed over decades.<sup>255</sup> Such technologies, when paired with smart meters, will enable people to reduce consumption from centralised generation, as detailed information is leveraged to manage usage.<sup>256</sup>

**One of the biggest hurdles to alternative technologies, although this is rapidly changing, is that initial costs are relatively high, and the benefit streams seem both uncertain and long term.**<sup>257</sup> As a consequence, some countries offer soft loans and financial support for installation, and balance such incentives with feed-in tariffs and penalties.<sup>258</sup> Another consideration is that the **accuracy of smart meters should be verified on a regular basis, meaning extra cost and hassle.**<sup>259</sup> In case of electric or gas heat pumps, due to the presence of an evaporator fan, there is a significant level of noise which some users might find disturbing.<sup>260</sup>

Another issue is that strategies of microgeneration will be highly variable between regions, meaning that specific guidance about optimal solutions might not be readily available to individual consumers. Furthermore the issue of digital information security emerges within the context of a smart metering system.<sup>261</sup>

*People residing in flats*

Generally speaking, individuals living in apartments usually have less disposable capital than those living in houses, and as a result, **solutions relating to energy retention efficiency (such as insulation) will be more attractive to this demographic due to lower purchase and installation costs.** In this regard, public financial support schemes such as the Heating Modernisation division of the **Warmth of Home Programme** in Hungary aim to drive the installation of heating systems employing condensing technology through investment in physical infrastructure. The reduction or elimination of cost related barriers to entry encourage the use of renewable energies and improve the energy performance of existing residential buildings.<sup>262</sup>

As with standalone houses, smart meters can offer real-time access to consumption data, being of particular use in the context of flats due to the diversity of living environments.<sup>263</sup> Also, combined heat & power systems have been identified as having a unique opportunity to create efficiencies, as they are independent from main grids, and can work continuously in case of grid-level blackouts.<sup>264</sup>

There is no getting around the fact that, especially in the context of a large development, the upfront costs of energy efficiency or renewable energy investment poses a significant barrier.<sup>265</sup> This is compounded by the fact that there is relatively long payback time for Renewable Heating and Cooling systems.<sup>221</sup> When you pair this reality with a lack of awareness, deployable technologies such as geothermal district heating languish on the planning board.<sup>267</sup>

*Early adopters – people open to innovation and new technologies*

This segment consists of environmentally conscious people who see modern heating technologies as a unique way not only to save energy, but also reduce air pollution.<sup>268</sup> It is also likely front of mind that new systems operate safer than the conventional ones, with further incentivization coming in the form of legislative requirements, as is the case in Sweden.<sup>269,270</sup>

Cost of entry is undoubtedly less of an issue in this segment, but remains a consideration.<sup>226</sup> More of a sticking point is that many of these technologies provide intermittent generation, meaning that the needs of the user are not always being met.<sup>272</sup>

**Business sector**

*Energy generation*

More and more, companies are turning to technology to acquire and retain customers, as well as reduce operating costs. **In many European countries, firms can even do one better by adopting green technologies, as there are financial incentives in place to encourage increased contribution**

**to emission reduction goals.**<sup>273,274</sup> This is supported by the enforceability of legislation which forcibly regulates emissions at both the producer and consumer ends.<sup>275</sup> As a result, power plants operated by companies also in the heating industry are generally using interoperable technologies with varying degrees of integration so as to ensure more efficient energy generation.<sup>276</sup>

Just as we saw on the individual level, one barrier to the introduction of new technologies are capital requirements. In the case of private enterprise, this couple with business uncertainty, meaning that downside risk often trumps upside potential in risk calculations.<sup>277</sup> Somewhat surprisingly, **the risks regarding investment in energy efficient technologies are considered high, with this perspective being as a result of uncertainties surrounding the technologies themselves.** Additionally, the lack of a trained workforce is proving worrisome for the industry.<sup>278,279,280.</sup>

This being said, in some countries, there is an increased residential demand for 100% renewable energy, and energy providers are not poised to be able to meet consumer preferences.<sup>281</sup> The regulatory environment is beginning to have a substantial impact on the adaptability of innovation, with the constant and rapid change of technology creating a complex and politically charged space.<sup>282,283</sup>

*Energy distribution*

As in the case of other agents involved in the provision of energy, improved data analytics and the opportunities of information technology are offering new possibilities to effectively address customer needs and create more targeted products. Moreover, **companies have the opportunity to manage supply and demand better.**<sup>284</sup> Particularly, there is a high consumer demand for continuous supply, which is currently driving innovation in this sector.<sup>240, 241, 242</sup>

Less positive is the reality that the adoption of new technologies may put the security and resilience of the entire system at risk. New technologies are often considered attractive, but they simply do not have the history and associated understanding of more traditional systems.<sup>243, 244</sup> What is more is that a lack of coordination in development means that variation may necessitate diverse, simultaneous distribution methods, leaving the possibility of prohibitive operating costs.<sup>290,291,292</sup>

*Infrastructure managers & providers*

Infrastructure managers and providers are governed by strict technical requirements, with existing standards motivating the industry primarily to search for improvements in infrastructure management.<sup>293,294,295</sup> It is predicted that while real time data collection and analysis will help to understand customers' consumption better, innovation will enable the reduction of transmission energy loss.<sup>296,297,298</sup>

it is likely that **in order to obtain the full benefits of innovation, it will be necessary to implement overall network upgrades, as well as engage in technology verification.** Such large scale overhauling will likely come at a high cost and be a complex process – which might lead to conflicts between the investors and users, especially when it comes to upgrading individual homes.<sup>299</sup> Other than these obstacles, we also have to consider both the lengthy payback time, as well as regulatory issues in some countries as potential sticking points.<sup>300,301,302</sup>

*Construction*

**Demand for the implementation of new technologies on the client side is driving innovation and adaptation in the construction industry,** a trend which is being helped along by high interoperability of technologies. For example, refurbishment and smart construction are effective, promoted ways in which to cut air pollution and greenhouse gas (GHG) emissions, as older buildings are responsible for a significant amount of harmful emission in Europe. As an example may serve Thermomodernisation Programme announced by the Polish government. The primary purpose of this initiative is to provide financial assistance to investors and households implementing thermomodernization and renovation projects.<sup>303</sup>



**Other than the end product, there is also room for improvement in the construction process itself, as there are several energy-intensive processes in the construction industry.** These oftentimes make use of fossil fuels, resulting in disproportionate production of high air pollution. Alternative fuels and innovative solutions will go a long way to correcting this, with more sustainable solutions likely to present considerable business opportunities.<sup>304,305,306,307,308,309,310,311</sup>

As with any disruptive innovation, although there may be opportunity for growth, economic and social changes threaten to hamper their success. For instance, the 2008 recession hit the construction sector hard, and with slow recovery, many firms are having trouble attracting fresh talent. What is more is that due to the complex nature of new technologies, proper communication between different stakeholders would be optimal, as this would ensure information transfer. **The challenge here is that the sector is fragmented, with low levels of cooperation between members of the supply-chain.** This, paired with a high degree of uncertainty regarding the level of return on investment will be difficult to surmount.<sup>312,313,314,315,316,317,318,319</sup>

*Other industries*

**One sector which will benefit from the wider acceptance of innovative solutions is the research and development industry,**<sup>320</sup> as other industries will look to R&D firms for scientific breakthroughs which may enable new technologies (e.g. through the increased stability of combustion catalysis).<sup>321,322,323</sup> Furthermore, research and development has the potential to reduce not only harmful emissions at the end of the pipe, but also the volume of dangerous substances used in the process itself.

Major shifts in how we heat will likely prompt job creation in the utility industry,<sup>324</sup> with additional sectors such as health and commerce also benefitting from the adoption of new technologies through lower overhead and greater certainty of supply.<sup>325</sup>

With both the changes in and benefits derived from improved heating solutions being largely systemic, a general lack of standardization and regulation may create significant barriers for all industries in terms of commitment to change.<sup>326</sup> Plausibly, this effect might be pronounced by coordination failures, as many stakeholders do not have strong incentives. However, growing importance of sustainable finance paradigm might induce businesses (at least public companies) to allocate more funds to greener solutions.

As one of the goals of these new solutions is to ensure supply security, the increased need for rare earth elements should be taken into consideration. Finally, although insurance companies may play an important role in managing physical and economic uncertainties,<sup>327</sup> risks related to cyber security and privacy will have to be carefully addressed.<sup>328</sup>

**Public sector**

*Central governments and their agencies*

**Central governments have largely thus far been motivated to adopt measures supporting innovations of the heating industry so as to ensure compliance with EU regulations, and achieve emission reduction targets.** With EU energy efficiency and low-carbon energy strategies targeting heating related innovations (e.g.: CHP penetration for CO<sub>2</sub> reduction),<sup>329,330</sup> several countries have already adopted measures focusing on this sector.<sup>331</sup> Paired with EU support, central governments are motivated by the opportunity to have alternative energy sources ensure both energy security and independence.<sup>332</sup>

As we have previously seen, regulation is a central element to the success of innovative technologies, playing roles varying from reducing uncertainty to raising public awareness. Yet, this requires better engagement with a variety of stakeholders, as important issues on the regulatory level remain a lack of transparency and inconsistency. **Another criticism, leveled against regulators is that policy has yet to respond to local needs,** which is considered to be due to *inter alia* the lack of information. From this, we may see how legislative changes at the national level should be born at least in part from regional initiative and dialogue.<sup>333,334,335,336</sup>



*Regional and local governments*

**Local governments are faced with a challenge in balancing job creation with lowering infrastructural maintenance and hopefully passing savings on to citizens.** While alternative heating provides an opportunity to increase energy efficiency and achieve targets, new heating technologies may offer positive environmental and economic impacts through emission reduction and fuel efficiency. Furthermore, smart technologies may present an answer to both the growing infrastructural demand, and in mitigating transmission losses found in current systems.<sup>337,338</sup> Promisingly, studies have shown that cities may be some of the most effective bodies in meeting GHG emission and waste reduction targets by focusing in on heating processes.<sup>339,340,341</sup>

Another worthy idea is Green Public Procurement – purchasing products and services that cause minimal adverse environmental impact. Governments by using their purchasing power to choose environmentally friendly goods, services and works, can make an important contribution to sustainable consumption and production.

However, with the high costs of entry, there is a political risk, as especially smaller local governments might find themselves financially overstretched. Moreover, **issues surrounding land use and visual pollution will have to be addressed, along with possible unemployment relating to restructuring.** The shift to more sustainable technologies and processes may create social and economic changes – the burden of which will fall primarily on local governments.<sup>342,343,344</sup>

*Other public services*

Overall, it can be noted that virtually all of the previously mentioned drivers are will be found across all public sectors, and fundamentally, possible actions can be distilled into: air pollutant emission reduction, and the increase of energy efficiency. Particularly though, economic motivation may be considered to be one of the most prominent incentives in case of heating, with building renovation and refurbishment benefitting many sectors.

Practically speaking, while alternative energy sources may serve as backup sources, or for powering non-essential equipment, an important aspect of heating innovation is likely to be its usefulness in social housing. By these means, district heating may be considered as a key element in meeting both EU environmental targets and national development goals.<sup>345,346,347</sup>

This being said, for many public sectors (such as healthcare), the need to maintain the continuity of power and heat supplies contract the possible applications of new technologies. Other general barriers include infrastructural and administrative challenges, as well as managing issues of cyber-security and personal data are crucial.<sup>348</sup>





# Smog and air pollution – impact assessment of feasible innovative solutions

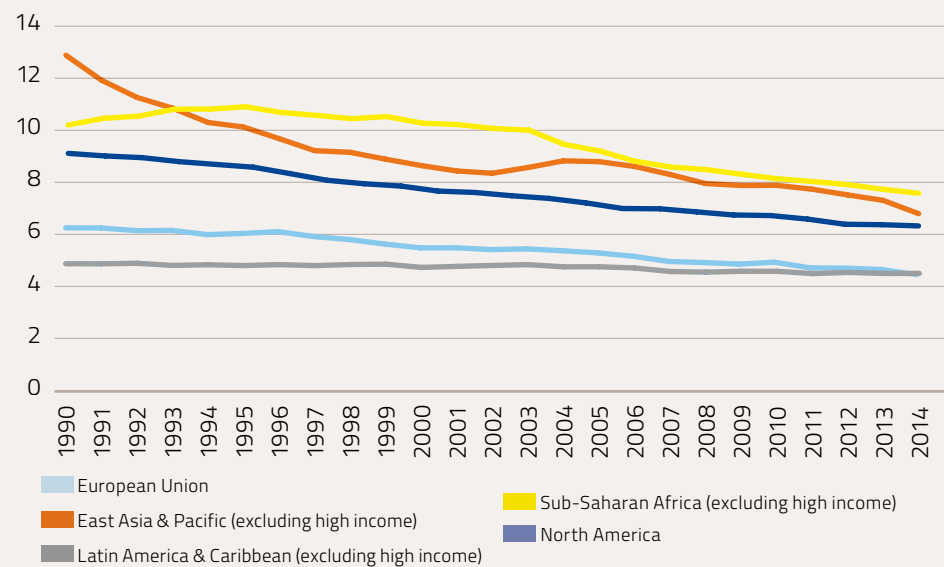
Here, we begin to enter the most critical section of this report with regards to what can actually be accomplished in the real world, as well as how we might envision this happening. In this section, we shall synthesize more succinctly the findings from our analysis of the environmental and financial impacts of investment. This will be accomplished by tying these takeaways more closely in with the theoretical and empirical findings on the relationship between economic development, energy use, and smog. This will in turn be linked more robustly to the approach of the overarching assessment, while retaining a focus on the critical fields of urban heating and transportation. Ultimately, all of these layered outputs will be fed into an econometric analysis of smog concentrations in European cities, thus providing additional source for our investment and policy recommendations.

## Economic development, energy use and smog – empirical relations

### Energy and transport intensity

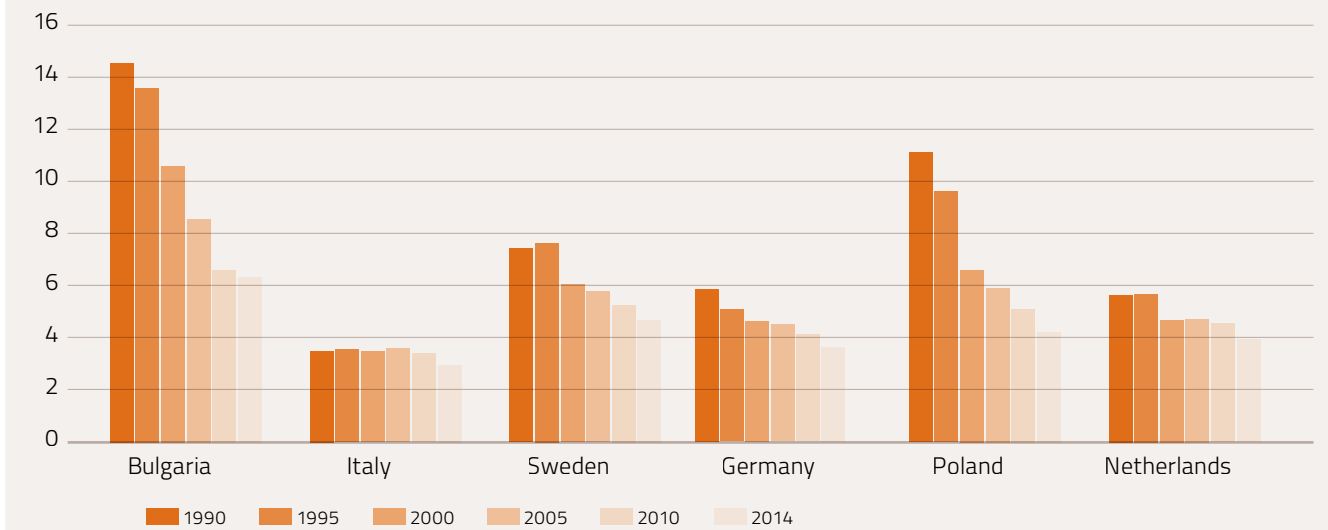
For many decades since the First Industrial Revolution, economic growth has been associated with a growing use of natural resources and energy, which led to vast damage in both the biosphere, and ambient air quality. Although this was the case both for market and centrally-planned economies, the latter recorded much lower productivity, (measured as generated GDP or Gross Value Added per resource or energy unit). It might be concluded that market-based incentives are the foundation for an improvement in productivity, as they drive the day-to-day activities and decisions of both households, and the business sector.

Figure 21. Energy intensity level of GDP (MJ/\$2011 PPP GDP)<sup>349</sup>



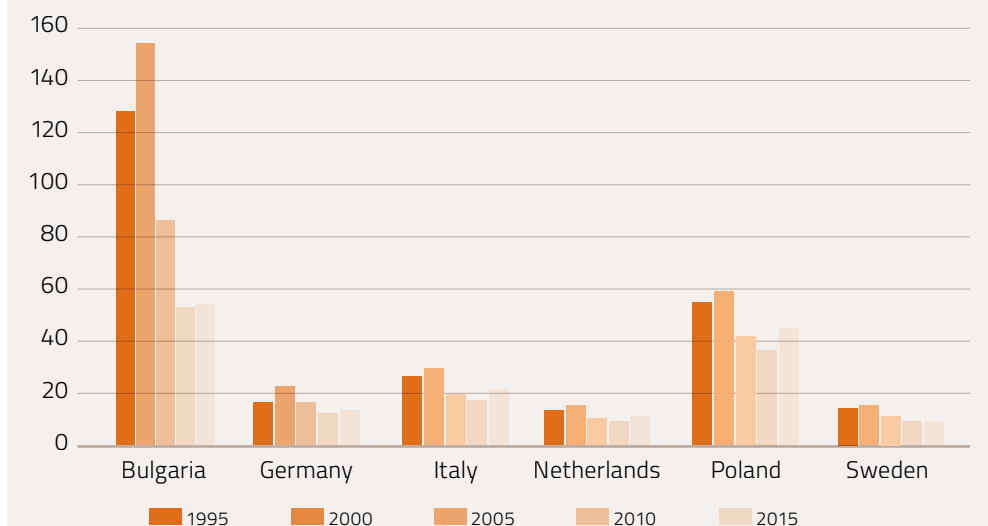
The economic growth of developed economies today is no longer driven by basic activities such as land use, the exploitation of low-value natural resources, and the leveraging of unskilled labour. Instead, we can observe a divergence over time between economic growth and energy use, pollution, and the demand for fossil fuels.<sup>350</sup> In Europe (Figure 21), the energy intensity dropped significantly in the last 25 years, most particularly in Eastern European countries (by over 56% in Bulgaria and 61% in Poland), but also in Western Europe (by 38% in Germany, 37% in Sweden, and 30% in the Netherlands).

Figure 22. Energy intensity level of GDP (MJ/\$2011 PPP GDP)<sup>351</sup>



Similarly, there is no causal relationship between transportation intensity and economic growth in developed countries. This might be explained by a high market saturation of transport services (which creates a necessity for efficient competition), and no need for the extensive development of the stock of vehicles so as to achieve economic growth (due to their relative performance).<sup>352</sup> Between 1998 and 2010, the transport intensity (defined as volume of freight or number of passengers carried to GDP) was stable in most EU countries, as well as Japan. Another category - namely China, Russia, Poland and the US actually achieved output growth through increased efficiency of deployment, with the economies of these countries generating more production per unit of transport service.<sup>353</sup> Consistent conclusions can be drawn from data relating the stock of passenger cars to GDP between 1995 and 2015 (Figure 23). These comparisons show us that transport intensity has been gradually falling since 2000, with a marginal rebound observed in 2015.

Figure 23. Passenger cars per one million units of current GDP (USD)<sup>354</sup>

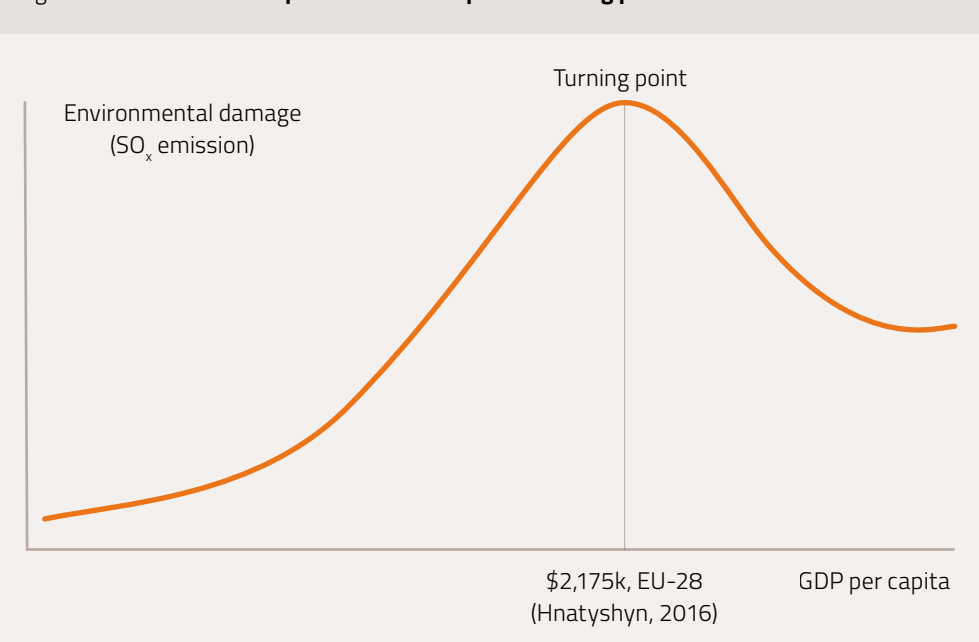




## Environmental Kuznets Curve hypothesis

Ultimately, many of the presented findings on transport and energy intensity can be related to a hypothesis called the **Environmental Kuznets Curve (EKC)**. The **Environmental Kuznets Curve hypothesis** deals with the empirical relationship between environmental quality, and the per capita income of a nation's inhabitants.<sup>356</sup> In line with the EKC hypothesis, the long-term relation resembles an inversed U-shape, indicating that the general state of the environment degrades in correlation to income growth only up to a certain income level. After this point, the state of the environment improves as per capita income continues to rise.

Figure 24. Theoretical shape of EKC and empirical turning point for the EU-28 economies<sup>357</sup>



The per capita income level at which environmental degradation starts to decrease is called the 'turning point,' with the advantage of the EKC hypothesis being that it is testable using econometric techniques. This being said, **evidence regarding its existence is mixed, and differs between particular pollutants.**<sup>358</sup>

The inversed U-shape of the curve has multiple theoretical explanations in the literature, but the most popular are the following:

- **growing societal need with income level** - societies pay little attention to environment issues during a rapid development phase, but at some point members begin to appreciate a clean environment more, and are willing to bear the additional cost of it;
- **industry- versus service-focused economy** - countries with low per capita income develop industry to enrich themselves, while richer economies shift to services, which usually are more environmentally friendly than industry and mining;<sup>359</sup>
- **technology investment** - technological improvements have been occurring in the industrial and construction sectors, paired with the rise of the renewable energy sector.

## Empirical evidence for the Environmental Kuznets Curve

Since the 1990s EKC has been a prominent research topic for economists, particularly within the context of studying CO<sub>2</sub> emissions. After reviewing the most recent scientific literature and collecting articles which contain econometric models examining the relationship between per capita income and smog components (such as SO<sub>x</sub>), the findings are best summarized by the on the next page.

## Smog and economic development – empirical evidence

M. Hnatyshyn (2016) performed a panel data analysis which confirmed the presence of EKC for SO<sub>x</sub> in the EU-28 countries during the period 1990–2013, and the turning point was found to be only \$2,175 of per capita income. B. Liddle (2013) examined the EKC for transport-related pollutants using cross-sectional data from 84 cities worldwide. He found evidence of EKC for NO<sub>x</sub> in the sample, with a per capita income of nearly \$16,000 as the turning point. However, he used

relatively old data (from 1995), likely because newer data was only available for much smaller number of cities. Hilber and Palmer (2014) used panel data from 75 cities from around the world for the period 2005–2011, examining the income-pollution relationship for the pollutants: SO<sub>2</sub>, PM and NO<sub>2</sub>. Their study did not find a presence of EKC, but rather another non-linear link between GDP per capita and air pollutants.

As we may see, although the global evidence for the existence of an EKC is mixed, a recent empirical study by Hnatyshyn (2016) delivered more positive findings, using data only from EU-28 countries.

## Econometric panel models of smog concentration in European cities

In order to check for the presence of an EKC, as well as uncover additional relevant factors in predicting smog intensity in European cities, three panel models were estimated:

- Model 1 with the explained variable concentration of PM<sub>10</sub>;
- Model 2 with the explained variable concentration of NO<sub>2</sub>;
- Model 3 with the explained variable number of days when PM<sub>10</sub> concentration exceed 50 µg/m<sup>3</sup>.

Figure 25. Sample of 67 European cities used for the econometric panel models and assessment of market potential



Source: Deloitte's elaboration based on Esri, DeLorme Publishing Company, Inc.

At the end of the day, none of the econometric models supported the presence of the EKC hypothesis within the context of the dataset of 67 European cities. What this means is that GDP does not necessarily (and likely does not outright) influence prevailing smog patterns in the EU. From this extrapolation, policymakers should thus not expect that further economic prosperity will resolve the problem without specifically targeted measures on the national or local level.

Thus, within the realm of policy, our recommendation is to support green growth, as the same models show that an increase in the share of renewable energy in the overall mix translates into a cleaner atmosphere:

- According to the Model 1, the share of renewable energy in gross final energy consumption reduces concentrations of PM<sub>10</sub> (effect was statistically significant);
- According to the Model 2, the share of renewable energy in gross final energy consumption has a statistically significant negative impact on concentrations of NO<sub>2</sub>;
- According to the Model 3, the share of renewable energy in gross final energy consumption has a statistically significant negative impact on the number of days when PM<sub>10</sub> concentrations exceed 50 µg/m3.

Continuing with the context of policy recommendations, it is important that our econometric results were derived from a wide geographic distribution of sample cities. Although the process of sample selection was based on a set of criteria directly related to data availability, the existing spatial dispersion in the sample is both remarkable and desirable. What is more is that the existence of many intangible or non-quantifiable variables which are country- or region-specific is perhaps a key reason that we cannot here apply the EKC model to European markets. More detailed results in this regard, as well as of the econometric study (Models 1,2 and 3) are presented in Appendix 2.

## Analytical approach and data source

Here, we shall present the way in which we treated the technical data relating to technological solutions in relation to their ability to tackle smog. Of course, the data sources implemented in the analysis will also be presented.

### Introduction - key steps

Our general approach consists of 4 major steps:

1. Firstly, relevant solutions in heating and transport were both mapped and grouped, resulting in the **technology tree** presented in Section 5.
2. Secondly, **a dedicated survey was conducted among a panel of technical experts in the fields of heating and transportation**. The aim of this endeavour was to compile a reference of critical indicators which would in turn allow us to assess the potential impact of each respective technology. Even more so, the attractiveness of investment was assessed from the perspectives of economic viability and technology readiness.
3. In the next step, an urban database was constructed, covering 67 cities in 26 EU countries. The goal here was to assess **market potential by means of statistics**.
4. Lastly, **a quantitative model was created to generate a numerical assessment of the potential impact on smog, the potential market, and technological attractiveness**. The model is based on our survey data, and is the major tool used for giving investment recommendations.

A more detailed description of the general approach is presented in Appendix 1. As such, we will move directly to the 4<sup>th</sup> step – in which the quantitative model was used to assess alternative investment opportunities in transport and heating.

Overall, the quantitative model has 3 sections that capture the environmental effect of studied solutions, their technological advancement, and market perspectives respectively. Ultimately, a greater weighting has been given to both technological and economic viability when considering the general attractiveness of a given solution. This being said, we present the results of the application of our model in both ways – namely using both 3 variables simultaneously and then honing in on 2 of the variables after compounding the technological and market considerations.

### Assessment of impact on emissions

In order to evaluate the impact on the emission of air pollutants by a given technology, a method to weigh different pollutants had to be established. The resulting approach used a system of weighting based on the share of a particular pollutant’s share of emissions from the total weight of emissions in the EU-28. The resulting values were then assigned ‘handicaps’ calibrated to the external costs to both health and the environment (as per the EEA assessment of impact).<sup>360</sup> The final values are presented in Table 5.

Table 5. **Weighting of air pollutant emissions per sector**<sup>361</sup>

Pollutant	Transport (applied weights)	Heating (applied weights)
SO <sub>x</sub>	0.01%	0.20%
NO <sub>x</sub>	62.33%	10.88%
PM <sub>10</sub>	19.43%	46.53%
PM <sub>2.5</sub>	17.95%	32.80%
BaP	0.29%	9.60%

Table 6. **Interpretation of emission reduction potential from the survey**

Survey values	Transport (applied weights)
1	0-5%
2	6-20%
3	21-50%
4	51%-99%
5	100%

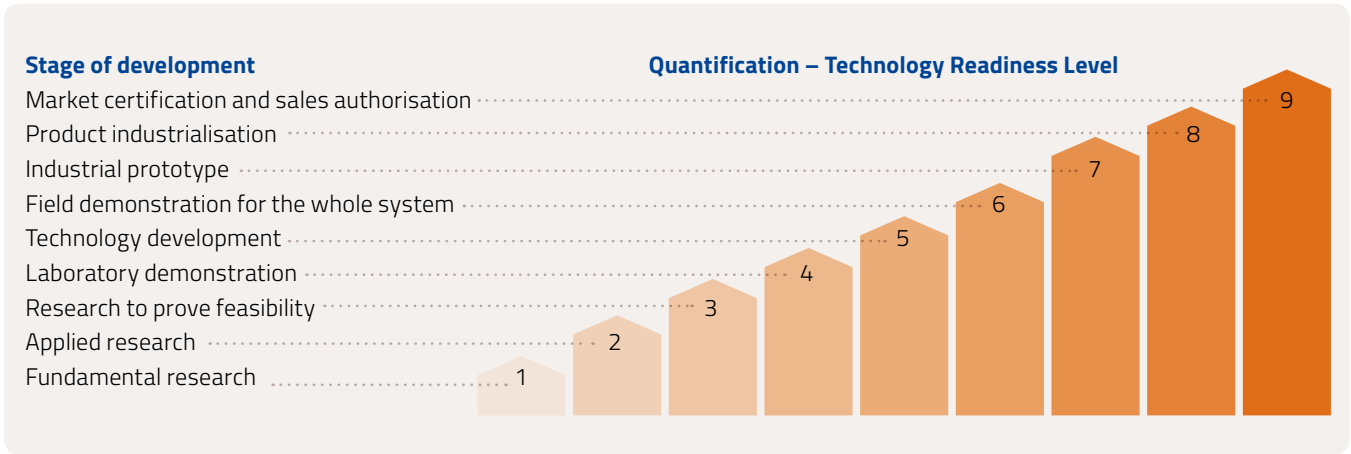
Source: Survey conducted by Deloitte.

### Assessment of technological attractiveness

Technological attractiveness is the first of two areas which are fundamental to a solution being an attractive investment. This important evaluation was assessed based on two variables, which were given equal weight:

**Maturity of the assessed technology** – which is a characterization of a technology’s readiness to be deployed effectively. This state was assessed on a 9-point scale, with the lowest being ‘basic principles observed,’ to the highest, in which ‘the actual system is proven in operational environment.’





**Dynamics of technological development** – assessing the pace of, and effort applied to developing a given technology further. Assessed on a 3-point scale, which are defined as:

- Long-term efforts lasting more than 5 years; no major breakthroughs
- Stable continuous activity within the field 5-1 years
- Recent breakthroughs and rapidly accelerating progress

### Assessment of market attractiveness

Market attractiveness, the second area of the utmost importance to investment attractiveness, was assessed based on two variables (equally weighted):

**Dynamics of market demand** – evaluated in the 5-year perspective, on a 3-point scale (small, stable, increasing)

**Possibility of market share increase** – evaluated for the period before 2025, for the following ranges:

- less than 1%
- 1-3%
- 4-10%
- 11-25%
- more than 25%

Finally, investment attractiveness was calculated as a product of market and technology attractiveness, and fitted to a 1-5 scale.

## Impact on smog and investment attractiveness – quantitative model results

**Quantitative results in this report represent a view and knowledge of the surveyed experts.**

Academics and practitioners were asked to provide the assessment on a chosen set of solutions till 2025. Hence, results as well as recommendations concern only mid-term perspective, which might be different than long-term outlook for selected solutions.

### Investment choices in the 2-dimensional space

According to the theory of optimisation, we can maximise or minimise only one situational variable that is subject to real-world constraint(s). For instance, an investor might choose to maximise their expected financial profits by assuming a certain level of risk (determined by their risk appetite). Conversely, they might minimise a level of risk for a proportional return. From this, the optimal balance of feasible risk and return in the capital market, or asset universe, can be graphically presented as an “efficient frontier.”

This being said, the expected return and risk associated with innovative projects is much more difficult to estimate than liquid, tradable assets (such as stocks of publicly listed companies, or bonds that are priced on regulated capital markets). To address the issues of non-transparent, or non-existent markets, as well as other market failures, we have employed both benchmarking and clustering, with the latter serving as a base for both the model results and subsequent recommendations.

Using the set of investible assets (investment opportunities), as well as attributed values from the survey, we are able to construct a “production-possibility frontier.” This in turn serves to link investments with the most beneficial ratio of one output to another. Other than this, the production-possibility frontier is a clear representation of potential trade-offs between outputs.

### Impact investing, the microeconomic production-possibility frontier, and the efficient frontier in the Modern Portfolio Theory

According to mainstream microeconomic theory, technological and market data, subject to our budget constraint, knowledge and resource scarcity, can show us what is possible to achieve from a financial standpoint. This axiom is referred to as the production-possibility frontier. Importantly, the applicability of this concept is not limited to “pure” economic outputs, but rather, it can also be applied to investment strategies undertaken by impact investors or public sector entities.

Impact and public investors often decide to achieve a hybrid goal, given by a function of two or more variables with assigned

weights. For instance, an entity might look to maximize its investment by putting a 50% weight on impacting smog, and 50% for expected financial returns. In order to determine the efficient frontier in line with a classic financial definition, investors must also first quantify the underlying risk. Summing up, an investor should be able to plot a graph with the expected return on a vertical axis (in our case it might be computed as a compound function of separate target variables), and investment risk on the horizontal (usually proxied by the historical volatility of market prices).

### Model results – interpretation

So as to properly assess the available technologies in relation to our needs, we need to first define which outputs are the most important in terms of achieving our goals. Ultimately, this will come down to balancing both market / technological attractiveness (and resulting profits), as well as impact on air quality. As impact investors are interested in delivering both financial and non-financial value, in the case of the InnoEnergy it would be in our best interests to present model results in a simplified, 2-dimensional space bearing a production-possibility frontier.

Model results are presented and clustered on Figures 26-29 in a two-fold way:

- **Production-possibility frontier** – to show the most promising technologies from both their total investment attractiveness and emissions reduction points of view. The total investment attractiveness is a function of market and technological attractiveness, and an optimal investment opportunity is one where the points sit on the frontier.
- **Bubble chart of market and technological attractiveness and impact on emissions** – used to split and compare the results for both market and technological as components of investment attractiveness. The bubble size indicates the potential impact on emissions.

Additional value of this approach is ensured by 2 specified clusters, both for transport and heating solutions.

Table 7. Summary of the final indicators used in the quantitative assessment

Final indicator	Relation to the indicators from the survey	Interpretation	Figure
Market & technological attractiveness (1)	Function of the Market attractiveness (2) and Technological attractiveness (3) specified below.	Total investment attractiveness, taking account for supply- and demand-side conditions and expectations.	Production-possibility frontier
Market attractiveness (2)	Function of an assessed dynamics of the market demand and possibility of market share increase by 2025.	Magnitude of market “pull” forces for innovative solutions	Bubble chart
Technological attractiveness (3)	Function of an assessed Technology Readiness Level and forecasted dynamics of technology development processes.	Magnitude of technological “push” forces for innovative solutions	Bubble chart
Impact on emission (4)	Function of an assessed potential impact on emission of SO <sub>x</sub> , NO <sub>x</sub> , PM <sub>10</sub> , PM <sub>2.5</sub> and Benzo(a)piren, weighted by unit external cost for each pollutant.	Socio-economic value of potential reduction of smog valuated by unit external costs and structure of emission.	Production-possibility frontier; Bubble chart

Source: Analysis by Deloitte

Results for Transport

According to this assessment, the creation of a greater ecosystem of electromobility is the best investment opportunity within transport sector from all of the three aforementioned perspectives. The most promising areas of investment include building the required **infrastructure for electromobility** (multiple car charging solutions, interconnected charging networks, fast chargers), and producing **electric vehicles**. This group constitutes **Cluster 1 (Electromobility)**, as marked by green dots and labels.

Table 8.a. Results for Transport – Cluster 1 (Electromobility) factsheets

Solutions in the cluster	Key business drivers	Key business barriers
Interconnected charging networks	R&D activities contributing to a decrease in both the battery and energy infrastructure costs as well as weight of vehicles	High upfront costs
Fast-chargers		Urban planning and regulatory limitations
Multiple car charging solutions		Customer’s negative expectations based on the limited availability of charging and refuelling infrastructure
Electric vehicles	Benefits for users like fueling at home, at work, overnight etc.	Limited electric grid capacity and interconnectivity
	Petrol prices tend to be volatile, while EV can make use of lower demand for electrical energy during night	Policy frameworks and lack of standardization
	Compliance with CO <sub>2</sub> and air pollution regulations	
	Preferential administrative treatment for alternative fuel vehicle users and financial incentives (tax and non-tax)	
	Favourable regulations; e.g. introduction of the requirement for new buildings to establish charging infrastructure on the premises	

Source: Analysis by Deloitte

Table 8.b. Results for Transport – Cluster 2 (Smart Public Transport System)

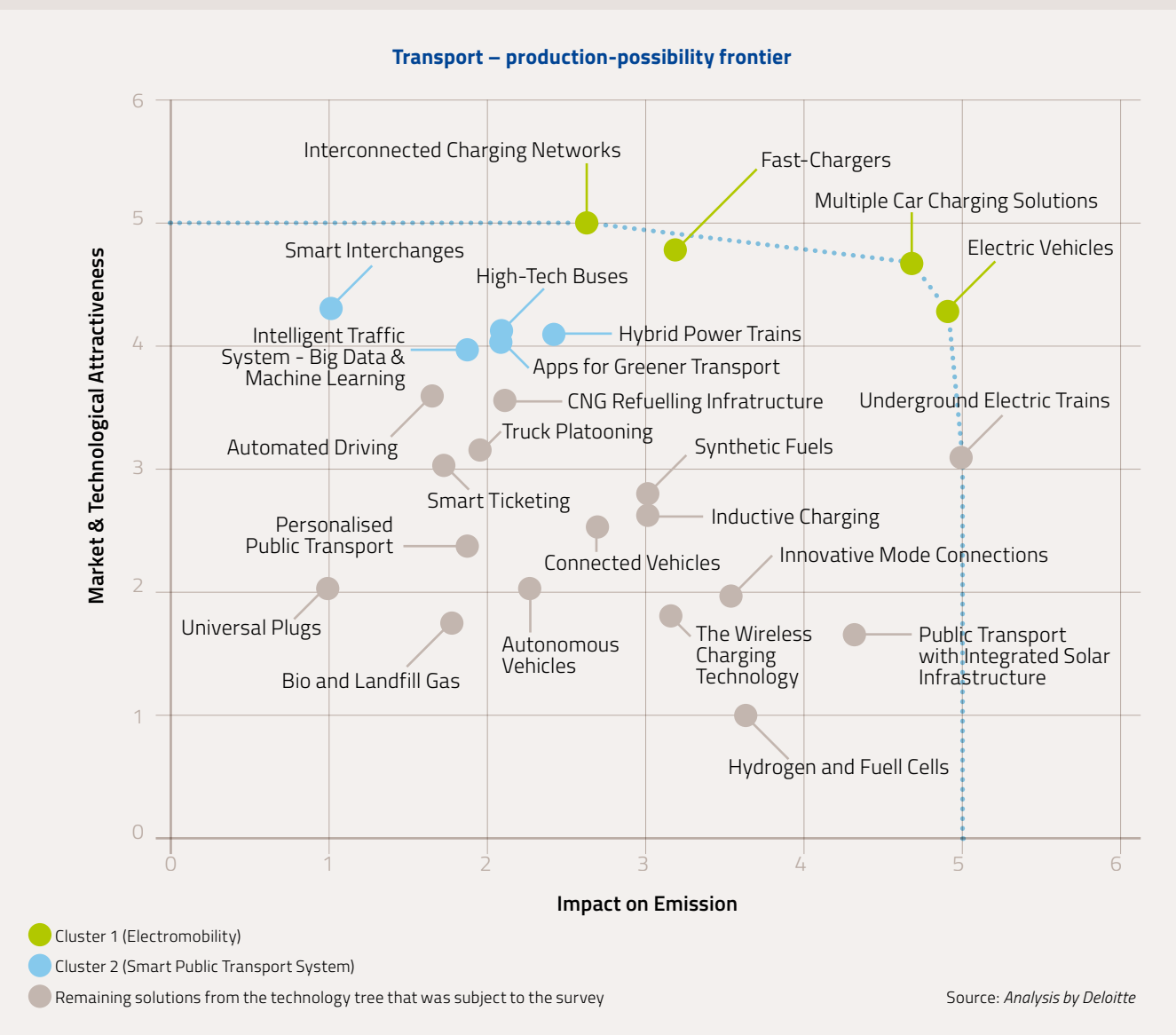
Solutions in the cluster	Key business drivers	Key business barriers
Smart interchanges	Potential for a decrease in both the number of accidents, and as a result, insurance costs	High infrastructure costs
High-tech buses		Standardisation issues
Hybrid power trains	Reduction of primary energy demand	Lack of consumer technological capabilities and awareness
Intelligent traffic systems - big data & machine learning	Potential for decreased congestion and optimisation of traffic	Cyber-security
Apps for greener transport	Efficient asset utilisation – reduced vehicle non-use time	Different expectations and requirements from different stakeholder groups
	Increased consumer demand for personalised services	
	Decreased operational costs	

Source: Analysis by Deloitte

In terms of joint market and technological attractiveness, group of solutions for public transport deserves some attention. Although they seem to represent vast range of applications and embodied technology, in fact we can summarise them as the Cluster 2 **Smart public transport system, marked with deep blue points and labels**. Even though all of them were assessed as an inferior to Cluster 1 (Electromobility), they serve very important market segment – urban

transport and supporting facilities. Thus, Cluster 2 might be attractive for investors that need better portfolio diversification or have experience and specific knowledge regarding public sector. Contrary to the Electromobility cluster, here investors should be ready to face noticeable trade-offs between market and technological attractiveness and environmental value. Apart from **smart interchanges**, that is characterized by lower emissions impact, other solutions from the cluster (**high-tech buses, hybrid power trains, apps for greener transport and intelligent traffic systems**) offer similar decent market and technological attractiveness.

Figure 26. Model results for Transport – production-possibility frontier, combined market and technological attractiveness (vertical axis) and impact on emission (horizontal axis)



Efficient frontier for the most promising technologies from both the total investment attractiveness and air pollutant emissions reduction points of view exchange:

- 1. Interconnected charging networks** – the highest expected investment attractiveness with almost twice lower influence on emissions than the other efficient frontier technologies
- 2. Multiple car charging solutions and Electric vehicles** – efficient combination of both investment outcomes and impact on air quality

Solutions relatively close to the efficient frontier:

- 1. Fast-chargers** – infrastructure for electromobility with higher market attractiveness than multiple car charging solutions and electric vehicles yet significantly lower impact on emissions.

Bubble chart represents another representation of market and technological attractiveness and impact on emissions. The size of the bubbles indicates that multiple car charging solutions and electric vehicles have the greatest influence on air quality, as well as underground electric trains and public transport with integrated solar infrastructure. Nonetheless much lower technological and market attractiveness of the latter two technologies excludes them from the worth-considering clusters. Values from axes implicates that fast-chargers are more attractive than electric vehicles. Yet performed trade-off between market and technological potential and emissions impact proved fast chargers to be on efficient frontier.

Figure 27. Model results for Transport – separate market (vertical axis) and technological attractiveness (horizontal axis) and impact on emission (bubble size)

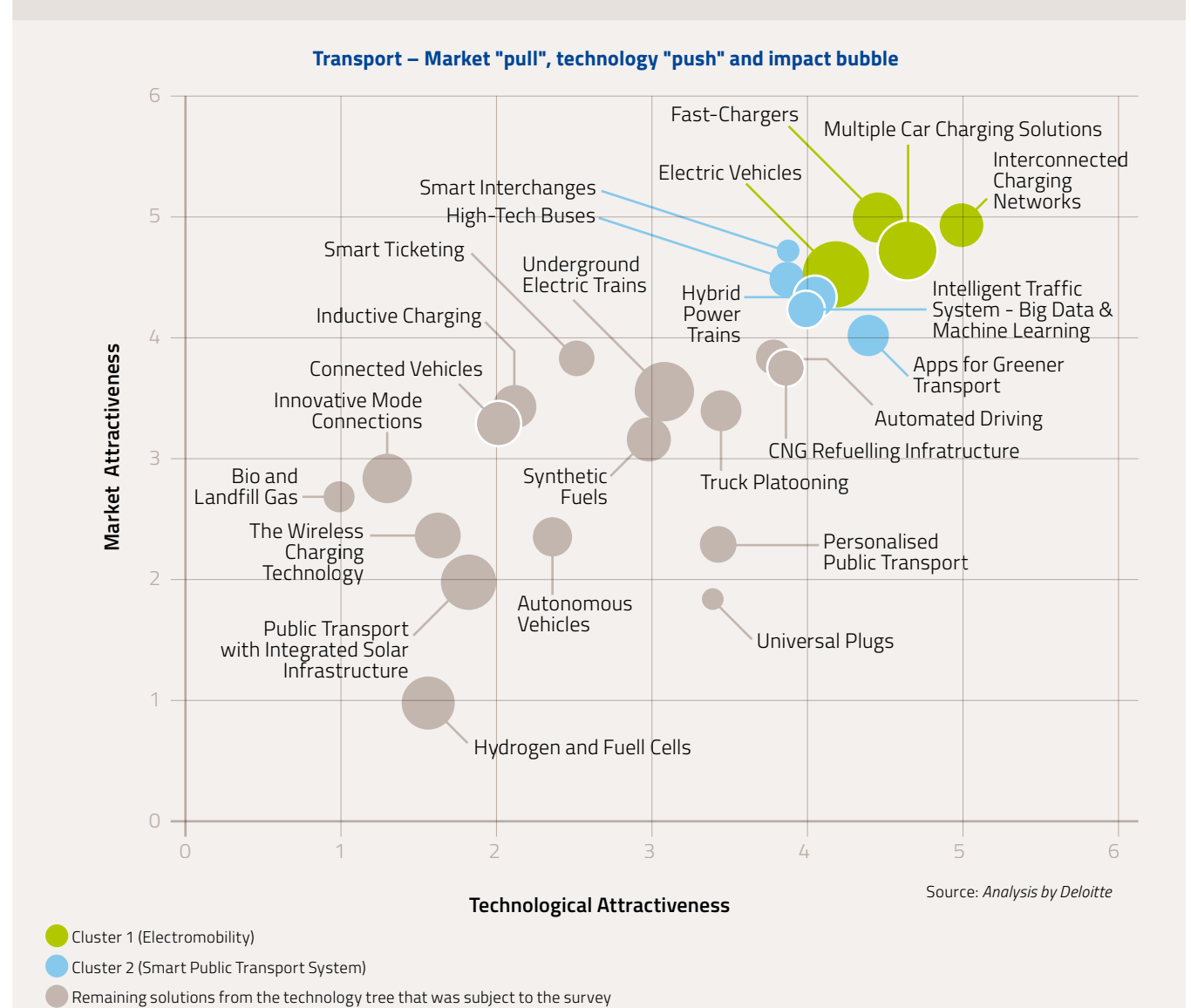


Table 9 compares technological solutions for transport with indication of a position on production-possibility frontier and allocated cluster. The winning technology are all from Cluster 1 – Electromobility.



Table 9. Summary – Results for Transport		
Production-possibility frontier - position	Efficient solution	Cluster
Max market and technological attractiveness	Interconnected charging networks	Cluster 1 (Electromobility)
Efficient combination of market and technological attractiveness and impact on emission	Multiple car charging solutions	Cluster 1 (Electromobility)
Efficient combination of market and technological attractiveness and impact on emission	Electric vehicles	Cluster 1 (Electromobility)
Max impact on emission	Underground electric trains	Underground electric trains
Source: Analysis by Deloitte		

Results for Heating

Our results indicate that there is a technology from each area on the production-possibility frontier: **heat generation** (solar thermal energy), **heat storage** (underground thermal energy storage) and **energy efficiency** (smart building energy management systems as well as distribution management systems). Even though underground thermal energy storage has the highest expected impact on air quality, due to its low market and technological attractiveness is not included in the cluster thus it is not further considered. The main barrier is the relatively slow development process. Contrary to the transport sector, there is no single cluster that dominates another possible one.

Relatively close to the frontier and thus included in clusters are the following: **energy positive windows, smart meters and sensible thermal energy storage**. From investment point of view, we can also add to the defined clusters items like: **demand controlled and multi zoned ventilation systems, fuel flexible CHP, low and ultra-low heating networks**. Their weaker performance is a function of relatively low technological readiness or average market perspective, according to our survey and quantitative model.

Table 10.a. Results for Heating – Cluster 1 (Smart Buildings) factsheet

Solutions	Key business drivers	Key business barriers
Smart building energy management systems	Dynamic development of smart grids and green office buildings	Multiple stakeholder engagement; lack of uniform standards
Energy positive windows	Increasing demand for personalised solutions	Lack of consumer awareness and technical capabilities
Smart meters	Optimisation of resource use	Potential limitations resulting from lack of flexibility in the existing built infrastructure
Demand controlled and multi zoned ventilation systems	Stringent building energy efficiency norms	Personal data and cyber-security issues
	Dynamic development of IoT and cloud technologies	Complex grid integration process
Source: Analysis by Deloitte		

Table 10.b Results for Heating –Cluster 2 (Distributed Generation and Storage Systems) factsheet

Solutions	Key business drivers	Key business barriers
Solar energy	Low operation costs	High upfront cost
Sensible thermal energy storage	Optimisation of resource use by utility providers	Lack of consumers’ technological awareness
Distribution management system	Ability to manage peak load more efficiently and avoid grid imbalances	Multiple stakeholders; complex level of interoperability between devices is needed
Low and ultra low heating networks	New business models; new partnership opportunities	Urban planning limitations
Fuel flexible CHP	Financial incentives	Lack of efficient price signals
	Dynamic development of smart grids	
	Compliance with the EU regulations	
	Increasing demand for the grid to integrate intermittent energy resources	
Source: Analysis by Deloitte		

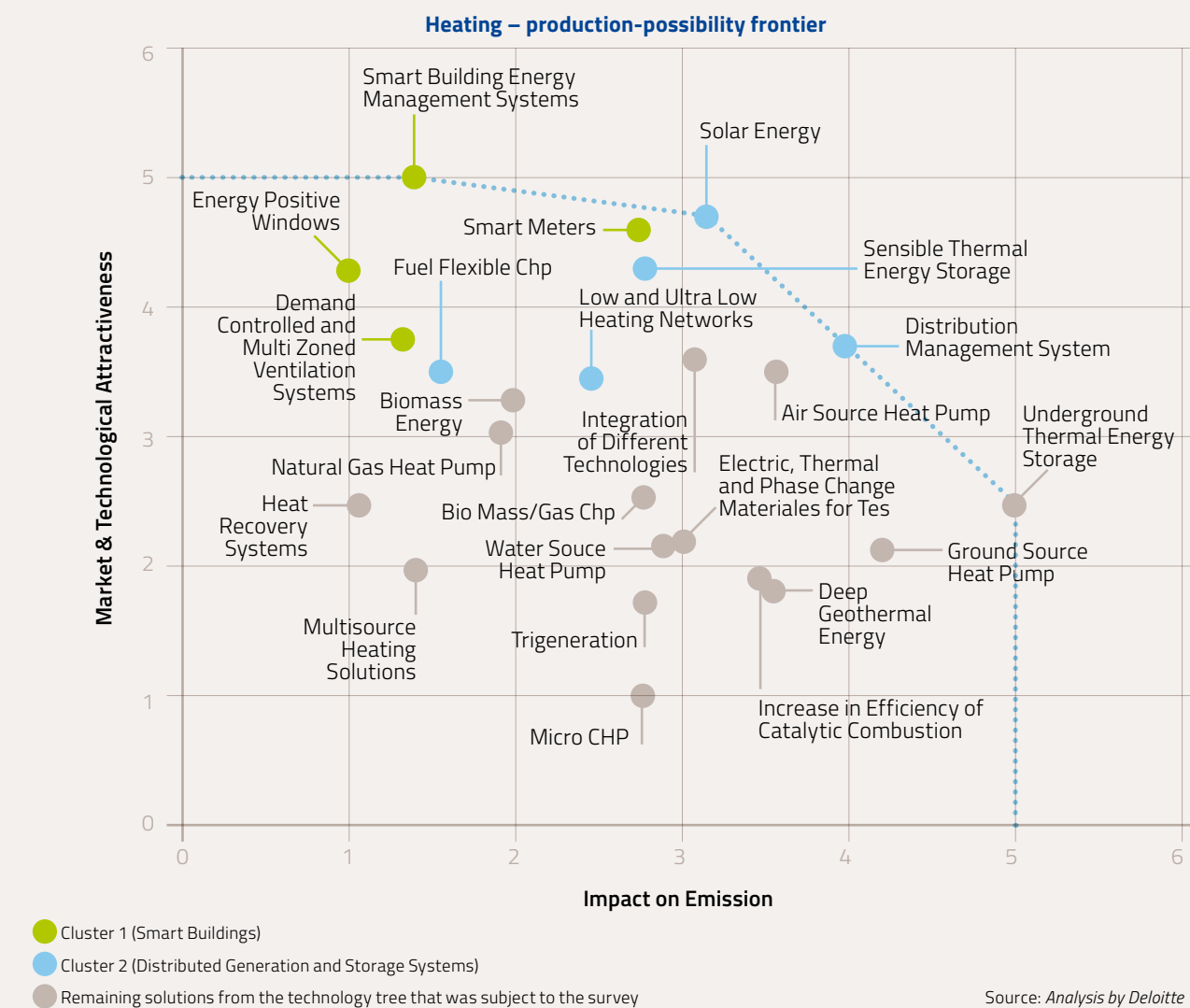
The production-possibility frontier for impact and investment attractiveness includes:

- **Smart building energy management systems** (highest expected investment attractiveness; the highest market attractiveness); designed to manage energy consumption of buildings, due to high costs of adoption it’s designed for large systems/buildings. It uses Internet of Things and cloud solutions, to analyse heating, ventilation, and air conditioning (HVAC) data, lighting data, and plug load data, and to lower energy consumption of the building
- **Solar energy** (efficient combination of impact and market perspectives) - similarly as for electricity grids, solar energy will allow for decarbonisation of the heating grid. At the residential and commercial building level, solar water heating and cooling can provide a sustainable, reliable and cost-effective option for end-users, especially in warmer climates.
- **Distribution management systems** (efficient combination of impact and market perspectives) have a potential to raise energy efficiency due to lower cost of outages, improved quality of distributed power and better monitoring capacities etc.

Relatively close to the frontier and thus included in Clusters are the following:

1. Smart meters – the closest technology to the efficient frontier. In our mode characterized with relatively high market and technological potential, and impact on pollution
2. Sensible thermal energy storage – lower market and technological attractiveness and similar emission impact compared to smart meters
3. Energy positive windows – attractive option yet emission impact is too low compared with efficient frontier.

Figure 28. **Model results for Heating – production-possibility frontier, combined market and technological attractiveness (vertical axis) and impact on emission (horizontal axis)**



The bubble chart allows to obtain different perspective on the results. Underground thermal energy storage is worth mentioning as its impact on emission is clearly the most significant although this technology is not mature enough yet to be considered attractive. Example of solar energy and smart meters can prove how technologies from different clusters can have similar potential. Air and ground source heat pump are characterized by high air pollution influence, yet their attractiveness on market does not meet expectations.

Figure 29. **Model results for Heating – separate market (vertical axis) and technological attractiveness (horizontal axis) and impact on emission (bubble size)**

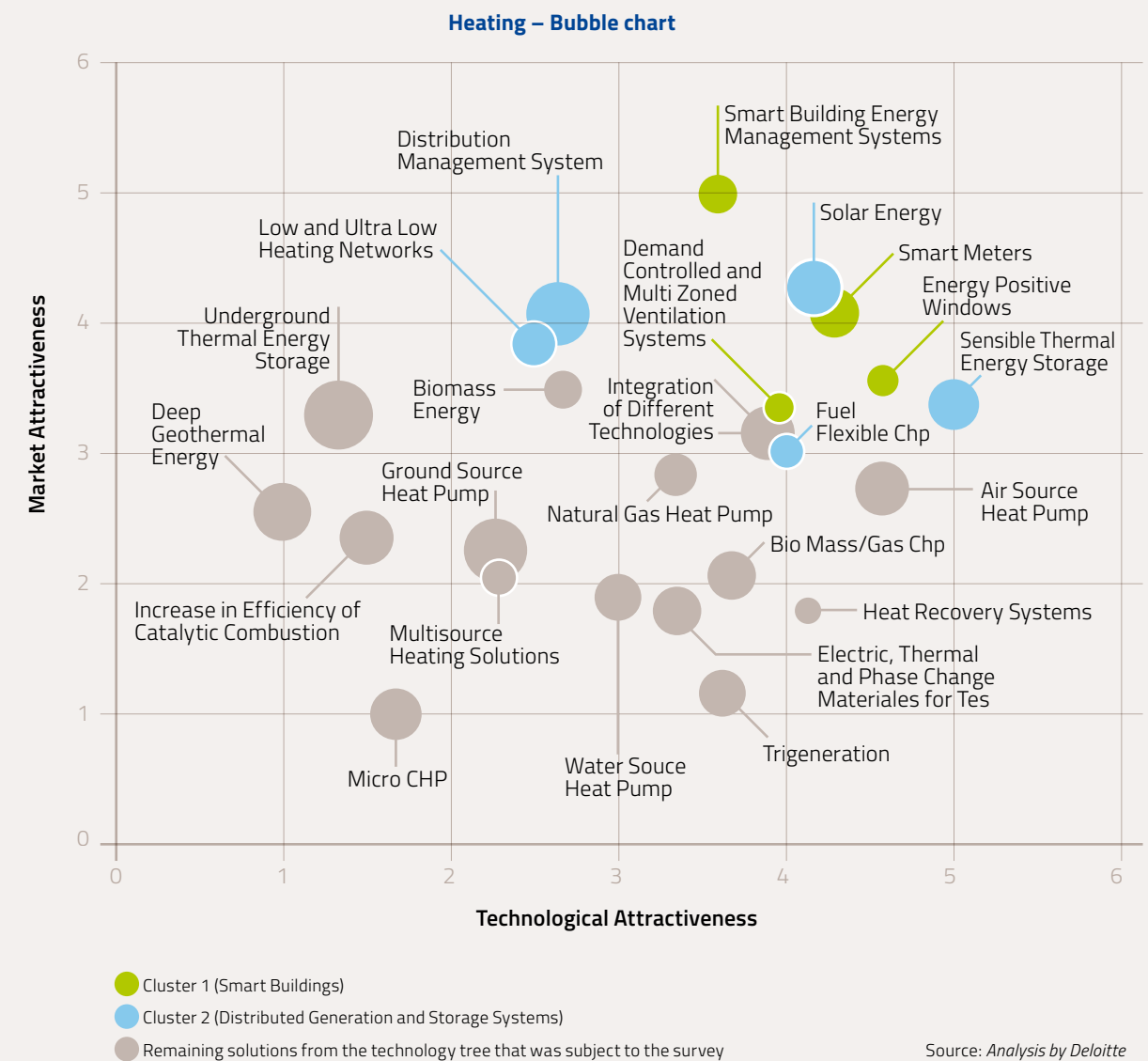


Table 11 with summarized results represents efficient frontier positions of three technologies and underground storage as a solution with the maximum overall impact on emission.

Table 11. Summary – Results for Heating		
Production-possibility frontier - position	Efficient solution	Cluster
Max market and technological attractiveness	Smart building energy management systems	Cluster 1 (Smart buildings)
Efficient combination of market and technological attractiveness and impact on emission	Solar energy	Cluster 2 (Distributed generation and storage systems)
Efficient combination of market and technological attractiveness and impact on emission	Distribution management systems	Cluster 2 (Distributed generation and storage systems)
Max impact on emission	Underground thermal energy storage	No cluster attributed
Source: Analysis by Deloitte		

Market potential assessment

Finally, using a sample of 67 cities in the EU, we looked at the relationship between smog and GDP levels. We also established variables describing the current state of the heating and transportation networks in the cities (e.g. state of buildings, share of people living in apartments), and counted the combined GDP of urban areas that met at least 4 out of 5 established criteria, and also extracted statistics regarding the population and share of the cities which met these same criteria.

Figure 30. Market potential assessment – criteria in transport area

Criteria	Variables for the Group 1: Electromobility and alternative fuels	Variables for the Group 2: Alternative transport solutions	Variables for the Group 3: Technologies supporting modal, organisational and behavioural shifts
Higher or equal to 3rd quartile	GDP per capita at current market prices by NUTS 3 regions, 2014, EUR	GDP per capita at current market prices by NUTS 3 regions, 2014, EUR	GDP per capita at current market prices by NUTS 3 regions, 2014, EUR
Higher or equal to 3rd quartile	Population on the 1st of January, total	Means of transport primarily used to go to work/training place: public transport	Population on the 1st of January, total
Higher or equal to 3rd quartile	Proportion of population aged 25-64 qualified at level 5 to 8 ISCED, from 2014 onwards	Means of transport primarily used to go to work/training place: public transport vs air pollution miPT	Proportion of population aged 25-64 qualified at level 5 to 8 ISCED, from 2014 onwards
Higher or equal to 3rd quartile	State of streets and buildings in my neighbourhood: (very satisfied or rather satisfied)	State of streets and buildings in my neighbourhood: (very satisfied or rather satisfied)	Means of transport primarily used to go to work/training place: public transport
Higher or equal to 3rd quartile	Means of transport primarily used to go to work/training place: car	The quality of the air in the city: (very satisfied - not at all satisfied)	Means of transport primarily used to go to work/training place: public transport vs air pollution miPT

Source: Analysis by Deloitte



Table 31. Market potential assessment – criteria in heating area

Criteria	Variables for the Group 1: Energy efficiency	Variables for the Group 2: Grid, storage, and other integrating solutions	Variables for the Group 3: Heat generation
Higher or equal to 3rd quartile	GDP per capita at current market prices by NUTS 3 regions, 2014, EUR	Average area of living accommodation - m²/person	GDP per capita at current market prices by NUTS 3 regions, 2014, EUR
Higher or equal to 3rd quartile	Old age dependency ratio (population 65 and over to population 20 to 64 years)	State of streets and buildings in my neighbourhood: (very satisfied or rather satisfied)	State of streets and buildings in my neighbourhood: (very satisfied or rather satisfied)
Higher or equal to 3rd quartile	State of streets and buildings in my neighbourhood: (very satisfied or rather satisfied)	Proportion of households living in houses	Proportion of population aged 25-64 qualified at level 5 to 8 ISCED, from 2014 onwards
Higher or equal to 3rd quartile	SA1022V - Average area of living accommodation - m²/person	Share of land (%): Discontinuous residential urban fabric	Share of land (%): Continuous residential urban fabric
Higher or equal to 3rd quartile	Proportion of households living in apartments	Proportion of population aged 25-64 qualified at level 5 to 8 ISCED, from 2014 onwards	Number of conventional dwellings

Source: Analysis by Deloitte

For each city from the sample and given criteria, we checked whether relevant value is higher or equal to 3<sup>rd</sup> quartile of sample distribution. In other words, we checked if particular city is among top 25% performers from the sample. If city met at least 4 out of 5 established criteria, it was included in calculation of potential market size.

Figures 32 and 33 show the results for heating and transport respectively. All of the analysed technology groups seem to have a far reaching ability to impact air quality in European cities. Strikingly, the cities that met the criteria in heating accounted for around half of the total GDP of the cities in the sample for all technology groups.

Figure 32. Market potential assessment: Transport

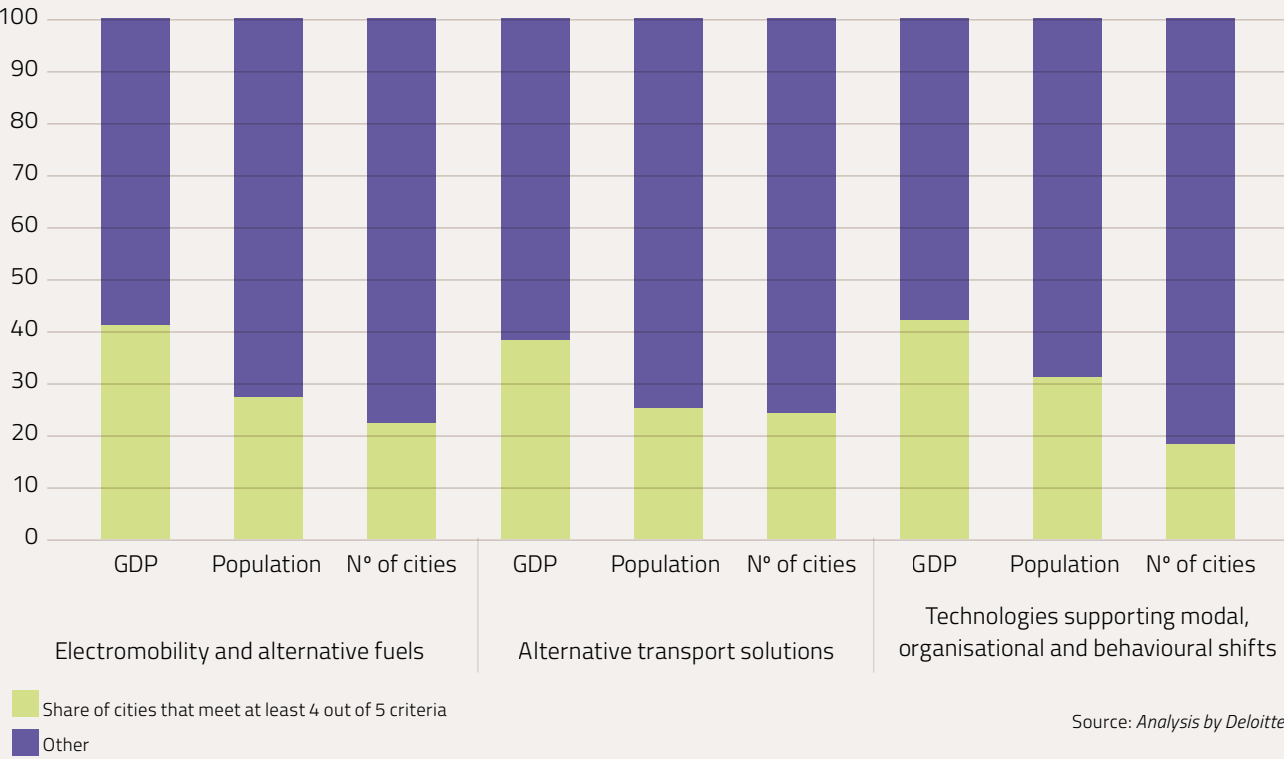


Figure 33. Market potential assessment: Heating





# Conclusions





1

Smog may attribute to even 1 in every 10 premature deaths in the world and over 400,000 premature deaths in Europe every year.

3

According to our simulated conservative scenario, European citizens might gain €183 BLN between 2018 and 2025, an equivalent of 1.2% of the forecasted GDP in the EU-28 in 2018. Such result is a combination of "Conservative 10% in 2025" Scenario regarding investments and supporting policies as well as middle value of estimated external costs.

2

Total external costs related to the health effects of smog are estimated at between €242 BLN and €775 BLN in 2020.<sup>362</sup> Such annual burden on the European economy is a function of premature deaths, rising healthcare bills, protracted illnesses, lower on-the-job productivity and more common work absences.

4

Cooperation with the private sector is a key element of effective policies to address air pollution. Public investment to boost innovative solutions can increase the overall benefit to society. Local and municipal governments can facilitate partnerships between government, research centres, and the industry.

5

GDP does not necessarily influence prevailing smog patterns in the EU. Policymakers should thus not expect that further economic prosperity will tackle the problem alone without specifically targeted measures on the national or local level.

7

Within transport sector, creation of the better ecosystem for electromobility is the best investment opportunity. This holds for the market, technological and emission reductions point of view. The most promising investment areas include building the infrastructure for electromobility (multiple car charging solutions, interconnected charging networks, fast chargers), and producing electric vehicles.

9

Within heating sector, the most promising solutions might be attributed to the Smart Building Cluster and Distributed Generation and Storage Systems Cluster. Particularly attractive for investors are the following: solar thermal energy, smart building energy management systems as well as distribution management systems. Underground thermal energy storage is the most efficient for investors that maximize potential impact on smog, though possibility of delivering it is a subject to significant technological risk.

6

Public awareness of the problem and its urgency is crucial to accept the burden of policies such as congestion charges. Moreover, citizens are more likely to take action on climate change if the co-benefits are emphasized. There is a direct correlation between a higher level of education, and concern about the environment.

8

The Smart Public Transport System Cluster is a valuable supplement to investment portfolio that allows risk diversification as well as serving very important markets. Moreover, there are no noticeable trade-offs between market and technological attractiveness and environmental value.





# Recommendations



## Call for action: smog costs the EU around 2.9% of its GDP every year

Europe has a pressing need of sustaining vigorous long-term economic growth which is likely to be slower due to unfavourable demographics. Shrinking labour force means that more and more Europeans have to work longer and be more productive if they want to, at least, preserve current quality of life. However, the current level of air pollution in Europe counteracts this necessary process, which generates tangible socio-economic costs.

### External costs of air pollution – estimated value for the EU

According to the analysis conducted by the European Commission, total external costs related to the health effects of smog are estimated at between €243 BLN and €775 BLN in the EU-28 in 2020.<sup>363</sup> Such annual burden on the European economy is a function of premature deaths, rising healthcare bills, protracted illnesses, lower on-the-job productivity and absences.

Although the European Commission's projection indicates noticeable downward trend since 2010, the pace of improvement will be much smaller in the coming years. Hence, BAU scenario (Business as Usual) is associated with a persistently high cost of externalities ranging between €224 BLN and €749 BLN in 2025, which is only 5-8% improvement against 2020.<sup>364</sup>

Average value of the external costs between 2018-2025 is equal to considerable € 475 BLN, which is on average 2.9% of forecasted annual GDP in that period (assuming the middle estimate of externalities).<sup>365</sup> After applying the lowest estimate, projected external costs for Europe are still alarming – account for 1.37% of average annual GDP.

Realisation of the passive BAU scenario is not inevitable nor desirable, as alternative trajectories based on an enormous technological progress are emerging. The scenarios considered in this report and presented below involve transparent, planned and well-managed cooperation between private sector and public authorities directed towards boosting innovations in transport and heating. In this context, cutting-edge solutions and proper public policies should be considered as a great opportunity, an “accelerator” for simultaneous improvement in health, economic, social, and environmental sphere.

### Potential impact of recommended solutions on the EU-28 economy: a scenario simulation

Simulation is based on the survey results regarding potential impact on emission as well as estimates of external costs of air pollution made by the European Commission.<sup>366</sup> In this report, we recommend to focus on investments in 4 key clusters:

1. Electromobility
2. Smart public transport systems
3. Smart buildings
4. Distributed generation and storage

A joint impact assessment of abovementioned clusters was performed with a use of 2 Scenarios regarding the pace of market and technological development:

1. “**Conservative 10% in 2025**” Scenario (10% of average market share in 2025)
2. “**Ambitious 25% in 2025**” Scenario (25% of average market share in 2025)

Both Scenarios assume that market penetration for all solutions within 4 clusters is equal to 1% in 2018. Then, this share is growing at a constant pace to reach target values – 10% or 25% for corresponding Scenarios.

Key input to this simulation was delivered by surveyed experts, who assessed potential impact on air pollution for given solutions. Hence, it was possible to estimate what could be the impact of X% market penetration of solution Y, comparing to a baseline solution.

Further assumptions to the model were derived from the abovementioned European

Commission's elaboration on external costs of air pollution as well as data on unit cost of air pollutants and sources of pollutants from the European Environmental Agency.<sup>367</sup>

Figure 34. Forecasted potential impact on the EU-28 economy from recommended investments versus European Commission's BAU Scenario (Net Present Value, aggregate 2018-2025, € BLN)

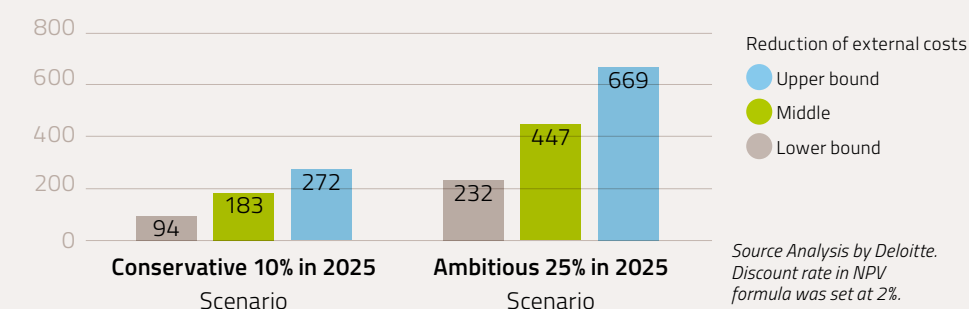
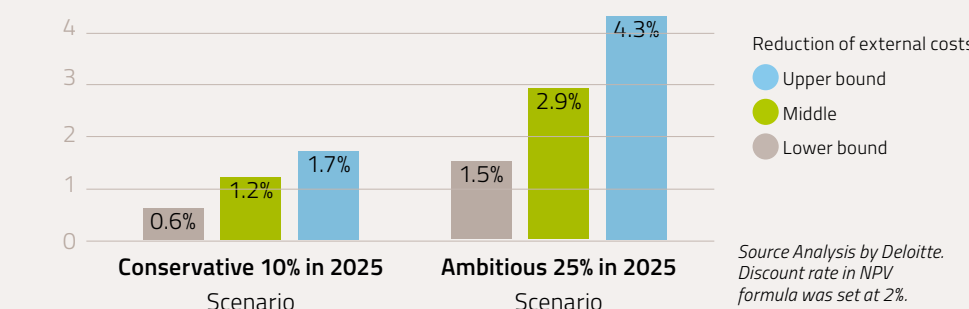


Figure 35. Forecasted potential impact on the EU-28 economy from recommended investments versus European Commission's BAU Scenario (Net Present Value, aggregate 2018-2025, % of GDP in 2018)



Finally, we are able to present 6 outcomes of potential impact on European economy that can be interpreted as reduced health-related total external costs of air pollution. These 6 values come from crossing 2 Scenarios related to market and technology developments and 3 estimates of the external costs – upper and lower provided by the European Commission and the one equal to their average (middle of the range). Main advantage of this approach is an ability to capture 2 major sources of uncertainty – proper estimate for external costs as well as future market and technological disruptions.

According to our simulated conservative Scenario, European citizens might gain 183 EUR BLN between 2018 and 2025, an equivalent of 1,2% of the forecasted GDP in the EU-28 in 2018. Such result is a combination of “Conservative 10% in 2025” Scenario regarding investments and supporting policies as well as middle value of estimated external costs. It should be underlined that even the lowest outcome means at least non-negligible net effect, supporting our call for a comprehensive anti-smog action which will boost investments and innovation in transport and heating sector.

## Investment recommendations

Investments are one of the most important levers for making long-lasting impact on the society and economy. In the world of limited resources and unlimited needs any investment decision should be backed by the best available knowledge and projections. Although we cannot precisely forecast investment outcomes for each selected project, we can largely limit and diversify investment risk by right portfolio choices.

Moving to the prospects of technological and non-technological innovative solutions, we can decompose key factors into exogenous (like demographics) and specific (or individual) ones. As a consequence, determining to what extent future pathways of innovative solutions are interrelated is an exercise that requires rather sophisticated set of assumptions on the unit level, that is for each solution.

**Because of this constraints, recommendations in this report are drawn on the group level (clusters), grasping the most important exogenous and group trends.** In this way we assume that investor through portfolio diversification is able to mitigate an impact of potential investment-specific shock (materialization of risk that is endemic to a single solution, project or asset in the portfolio).

How to interpret investment recommendations

Investment recommendations in this report are a direct product of performed survey and chosen analytical approach. While assumptions and technical notes regarding methodology are presented in other parts of the report, they should be supplemented by the following clarifications:

- 1. Investment recommendations are formulated on the group level (clusters),** thus they are more specific than hypothetic ones based solely on the exogenous megatrends that shape transport and heating. At the same time, they are more general than typical investment recommendations “buy” or “sell” concrete asset after reaching some price level.
- 2. Investment recommendations in this report represent a view and knowledge of the surveyed experts only..** Academics and practitioners were asked to provide the assessment on a chosen set of solutions till 2025. Thus, investment recommendations in this report concern only mid-term perspective, which might be different than long-term outlook for selected solutions.
- 3. Investment and policy recommendations should be read as a “call for action”** by improving market, societal and regulatory environment for the selected groups (clusters) of solutions.
- 4. Within recommendations we do not select one optimal technological or non-technological solution.** It is simply because each investor have its own preferences towards different goals and values. In our case we need to choose between outputs that might be produced by assessed solutions: market and technological attractiveness and impact on air quality.

**Ultimately, 18 selected solutions to watch from 4 recommended clusters are presented with additional insights from the survey.** Like it was stated before, we do not adjudicate which one is the “top of the top”, as it should be done by investors that have own strategies on concrete markets, geographies etc., not mentioning internal investment strategies and risk profiles. Instead, **we recommend tracking market and technological developments related to the solutions mentioned below.**

Table 12. Summary of the investment recommendations by 4 clusters

Electromobility	Smart Public Transport System	Smart Buildings	Distributed Generation and Storage System
Interconnected charging networks	Smart interchanges	Smart building energy management systems	Solar energy
Fast-chargers	High-tech buses	Energy positive windows	Distribution management system
Multiple car charging solutions	Hybrid power trains	Smart meters	Sensible thermal energy storage
Electric vehicles	Intelligent traffic system – big data & machine learning	Demand-controlled and multi-zoned ventilation systems	Low and ultra-low heating networks
	Apps for greener transport		Fuel flexible CHP

Source: Analysis by Deloitte

Investment recommendations for Electromobility cluster

Basing on our model results, we recommend to consider following solutions from the Electromobility cluster:

- Interconnected charging networks
- Fast-chargers
- Multiple car charging solutions
- Electric vehicles



Table 13. Selected solutions to watch from Electromobility cluster

Selected solutions to watch from Electromobility cluster	Economic environment	Consumer readiness level	Regulatory framework	Reliance on public support by 2025	Technological attractiveness	Market attractiveness	Impact on emission
Interconnected charging networks	4.00	4.00	4.00	2.33	5.00	4.93	2.64
Fast-chargers	4.14	4.29	4.00	3.00	4.46	5.00	3.21
Multiple car charging solutions	4.33	4.00	4.00	2.33	4.65	4.74	4.70
Electric vehicles	3.62	4.00	3.85	3.83	4.18	4.53	4.92
Reference scale	1 – long-term barriers; 3 – neutral; 5 – enabling	1 – long-term barriers; 3 – neutral; 5 – enabling	1 – long-term barriers; 3 – neutral; 5 – enabling	1 – heavy reliant; 3 – some forms needed; 5 - no reliant	1 – relatively low; 3 – average 5 - relatively high	1 – relatively low; 3 – average 5 - relatively high	1 – relatively low; 3 – average 5 - relatively high

Source: Analysis by Deloitte based on the survey.



Investment recommendations for Smart public transport system cluster

Basing on our model results, we recommend to consider following solutions from the Smart public transport system cluster:

- Smart interchanges
- High-tech buses
- Hybrid power trains
- Intelligent traffic system – big data & machine learning
- Apps for greener transport



Table 14. Selected solutions to watch from the Smart public transport system cluster							
Selected solutions to watch from Smart public transport system cluster	Economic environment	Consumer readiness level	Regulatory framework	Reliance on public support by 2025	Technological attractiveness	Market attractiveness	Impact on emission
Smart interchanges	4.00	4.00	4.00	2.33	5.00	4.93	2.64
High-tech buses	4.14	4.29	4.00	3.00	4.46	5.00	3.21
Hybrid power trains	4.33	4.00	4.00	2.33	4.65	4.74	4.70
Intelligent traffic system - big data & machine learning	3.62	4.00	3.85	3.83	4.18	4.53	4.92
Apps for greener transport	3.75	3.50	4.33	4.33	4.41	4.06	2.10
Reference scale	1 – long-term barriers; 3 – neutral; 5 - enabling	1 – long-term barriers; 3 – neutral; 5 - enabling	1 – long-term barriers; 3 – neutral; 5 - enabling	1 – heavy reliant; 3 – some forms needed; 5 - no reliant	1 – relatively low; 3 – average 5 - relatively high	1 – relatively low; 3 – average 5 - relatively high	1 – relatively low; 3 – average 5 - relatively high

Source: Analysis by Deloitte based on the survey.

Investment recommendations for Smart buildings cluster

Basing on our model results, we recommend to consider following solutions from the Smart buildings cluster:

- Smart building energy management systems
- Energy positive windows
- Smart meters
- Demand controlled and multi zoned ventilation systems



Table 15. Selected solutions to watch from the Smart buildings cluster							
Selected solutions to watch from Smart building cluster	Economic environment	Consumer readiness level	Regulatory framework	Reliance on public support by 2025	Technological attractiveness	Market attractiveness	Impact on emission
Smart building energy management systems	3.87	3.75	3.12	3.29	3.58	5.00	1.40
Energy positive windows	3.25	3.75	3.00	1.67	4.58	3.56	1.00
Smart meters	2.80	3.40	2.80	3.00	4.29	4.08	2.75
Demand controlled and multi zoned ventilation systems	3.25	3.75	3.50	4.00	3.96	3.32	1.34
Reference scale	1 – long-term barriers; 3 – neutral; 5 - enabling	1 – long-term barriers; 3 – neutral; 5 - enabling	1 – long-term barriers; 3 – neutral; 5 - enabling	1 – heavy reliant; 3 – some forms needed; 5 - no reliant	1 – relatively low; 3 – average 5 - relatively high	1 – relatively low; 3 – average; 5 - relatively high	1 – relatively low; 3 – average; 5 - relatively high

Source: Analysis by Deloitte based on the survey.

Investment recommendations for Distributed generation and storage systems cluster

Basing on our model results, we recommend to consider following solutions from the Distributed generation and storage systems cluster:

- Solar energy
- Distribution management system
- Sensible thermal energy storage
- Low and ultra low heating networks
- Fuel flexible CHP



Table 16. Selected solutions to watch from the Distributed generation and storage systems cluster							
Selected solutions to watch Distributed generation and storage system cluster	Economic environment	Consumer readiness level	Regulatory framework	Reliance on public support by 2025	Technological attractiveness	Market attractiveness	Impact on emission
Solar energy	3.85	4.00	3.77	2.83	4.16	4.28	3.16
Distribution management system	3.00	3.33	3.33	2.33	2.64	4.07	4.02
Sensible thermal energy storage	3.40	3.40	3.75	4.33	5.00	3.36	2.80
Low and ultra low heating networks	3.50	3.33	3.20	2.00	2.50	3.83	5.46
Fuel flexible CHP	3.00	3.60	3.25	3.50	4.00	3.02	1.56
Reference scale	1 – long-term barriers; 3 – neutral; 5 - enabling	1 – long-term barriers; 3 – neutral; 5 - enabling	1 – long-term barriers; 3 – neutral; 5 - enabling	1 – heavy reliant; 3 – some forms needed; 5 - no reliant	1 – relatively low; 3 – average 5 - relatively high	1 – relatively low; 3 – average; 5 - relatively high	1 – relatively low; 3 – average 5 - relatively high

Source: Analysis by Deloitte based on the survey.

Policy recommendations

In this part we formulate four high-level policy recommendations that summarize lessons learned in the matter and more general conclusions from economic and social research. Later on, policy recommendations for clusters aim to correspond with a specific barriers and challenges to innovation adaption and new investments.

General policy recommendations

Green and sustainable growth as an overarching goal

*Green growth should be a key direction for private and public sector as it increases a quality of life for current and future generations. This requires good coordination across all environmental policies and linking them with an incumbent socio-economic context.*

In the overall policy context, **we recommended to support the green growth**, as our outcomes show that increasing share of renewable energy translates into cleaner atmosphere. According to our econometric estimates on the sample of European urban areas, **sustaining or even boosting GDP growth will not lead to a cleaner air by itself**. However, possibility of reverse effect should be taken into account by policymakers – i.e. that smog is a hurdle for long-term economic growth, negatively impacting labor supply and human capital accumulation. It is important to identify the co-benefits in combating air pollution and other environmental issues, such as climate change, biodiversity loss, and address them effectively with specific policy instruments. Not only synergies but also trade-offs should be recognised. In order to do this, **it is crucial to improve the collection and analysis of co-benefits and trade-offs data**.

Sufficient room for markets with a smart interventions

Smart balance of market-based instruments and top-down approach is needed to address potential trade-offs between securing important goods like: economic welfare, mobility, air quality, health, ecosystems, affordable housing, cheap energy etc.

**Cooperation with the private sector is key. Hence, we underline the importance of facilitating development of sustainable finance and impact investing**, a paradigm that attempts to address abovementioned issues and trade-offs. Market bottom-up forces cannot be substituted as a device for constant technological advancement, and by the same token we need the economy of scale or positive leverage that only financial sector can provide. However, modern financial markets sometimes generate externalities like boom and bust cycles that have an adverse effect on other sectors. Hence, there is a sound rationale for the state to assure that certain level of environmental, social and governance (ESG) factors are included in investment decision-making process.

Moreover, public investments are important supplements to private-led ones, especially in areas where social returns might be substantially larger than private. Heating and transport sector are good illustration of such phenomena. However, while combating smog, national and municipal governments need to address critical issues: energy poverty and influence of strong energy lobbying groups that may campaign against environmental policy.

Education and social awareness as foundation for successful adoption of green innovations

Strengthening statistical capacity is fundamental for improving the process of planning and executing private investments as well as evidence-based policies. Decentralized data sources provided by sensors, apps and intelligent devices might largely reduce information asymmetry and in effect boost innovation and investments.

**We recommend to support investments in expanding modern decentralized sources of data on buildings, urban infrastructure, vehicles, technologies** and other important assets, flows or



characteristics that impact local structure of transport system and energy sector. High-quality data sources generate positive externalities, in other words – have many features of public goods. We are witnessing the beginning of the Fourth Industrial Revolution. Its aim is to (as the previous ones) is to increase productivity and better adapt the product to the needs of recipients. Changes related to the commercial use of the latest technology acquisitions, digitization, artificial intelligence, sensors, biomaterials, the ability to analyze gigantic amounts of data – significantly affect the production and consumption patterns. If there is a lack of strong private incentives, we recommend to provide public funds for constructing and sharing databases. As a supplement, performing broad meta-analyses and empirical assessments with on-site surveys is highly recommended.

**Enhanced statistical framework and new data sources to induce innovative activities**

Investing in education and raising social awareness should be one of the priorities in public agenda, but also a responsibility of business and NGO sector. Air quality policies should be seen and promoted within the wider socio-economic spectrum so as to ensure that the measures implemented are adequate.

Public awareness of the problem and its urgency is crucial to accept the burden of policies such as congestion charges. Awareness helps people see the overall societal benefits of such policies, and makes them more willing to accept the restriction that these policies impose. **It is recommended to start from education and addressing specific socio-economic needs that might refrain from supporting green policies or adoption of innovations.** In this context, poverty and exclusion requires particular attention.

**Policy recommendations for the 1<sup>st</sup> Cluster: Electromobility**

- 1. Empower the role of private sector in urban planning**, both inhabitants and business sector, while providing incentives for sustainable transport solutions. Assure that potential trade-offs between demand for mobility, emission, economic efficiency and social inclusion are managed in a way that is socially acceptable and thus sustainable.
- 2. Minimize an investment risk through improvement of regulatory framework** for new investments in electric grid, storage and interconnectivity. **Public policy uncertainty should be limited by a national legislation** that on the one hand defines boundary conditions for support schemes, and on the other hand leave some room for local “policy optimization” based on social preferences.
- 3. Ensure right regulations, human capital and other prerequisite resources for boosting PPP projects** in the area of infrastructure, grid and storage. **Review the coherence and completeness of private property regulations** and amend any loopholes that might pose a problem of market failures, particularly externalities. For instance, good regulations should address a trade-off between full accessibility of infrastructure for alternative fuels and rights of private investors.
- 4. Raise social and consumer readiness through campaigns** showing technological progress and long-term “value for money” embodied in EV and public or private infrastructure.
- 5. Increase a number of policy controls, consider stricter regulations concerning emission standards** that will be executed during mandatory maintenance overhaul.

**Policy recommendations for the 2<sup>nd</sup> Cluster: Smart public transport system**

- 1. Analyze with an external financial auditor all the key elements of local governments’ public finance that finally translate into ability to finance long-term transport investments.** Compare possible supply of investment projects with an estimated local demand for sustainable and reliable transport services. In case of large imbalance, review whole transport policy in the area, focusing on pricing, non-pecuniary factors, social preferences and habits.
- 2. Check whether the public investments do not crowd out private ones. Considered should be, for example, privatization or PPP, PPP for some parts of infrastructure** if it might increase economic efficiency, boost investments, reduce burden for taxpayers or mitigate traffic congestion through “making users and polluters pay”. Support sharing economy and similar business models based on asset renting.

- 3. Eliminate bottlenecks in transport system and distortionary solutions in regulatory framework that lever total social costs of mobility, including environmental damages.** Check whether regulations, taxes or other non-market conditions do not discriminate greener transport modes and make them less competitive due to the transferred excessive costs, supply constraints, lower reliability and accessibility etc. Introduce incentives for cycling and other forms of zero-emission mobility more attractive.
- 4. Support modernization of public and private bus fleet, rolling stock** etc. by replacing old units with hybrid or electric motors, as well as alternative fuels like biogas.
- 5. Facilitate innovation through creating attractive environment for startup scene.** Promote cooperation between innovators that offer smart solutions and state-owned enterprises, especially infrastructure managers and carriers.
- 6. Lead a transition towards smart and greener transport in a way that does not exclude any stakeholders or communities.** Respond to specific needs and expectations raised by inhabitants, tourists, investors and other.
- 7. Gain support for smart mobility solutions via education** that should start in kindergartens. Address specific needs of less educated and elder population, which might not be accustomed nor have skills to reap benefits of innovations.

**Policy recommendations for the 3<sup>rd</sup> Cluster: Smart Buildings**

- 1. Make an audit of existing building substance** focusing on potential impact of installing smart technologies, thermomodernization and mapping key barriers for them.
- 2. Improve or extend census data reporting systems, which will create a basis for innovations as well as evidence-based policies** in the area of housing, energy and environment. Particularly such system should be able to serve more sophisticated economic or econometric models with a spatial component, which are very useful for analyses of air pollution exposures, real estate market etc.
- 3. Consider introducing more restrictive energy efficiency norms for buildings, individual heating appliances and fuel quality standards.** Assess the cost and benefits of financial incentives for greening the roofs, walls and private gardens as some of them might produce external benefits that are larger than private ones. Additionally, study the potential net benefit of support for prosumers.
- 4. Raise social and consumer readiness through campaigns** showing possible savings and positive impact on health and environment. Invest in education showing applications of fast developing groups of solutions like Internet of Things, cloud technologies and learning algorithms. Present additional value for households – flexibility and personalization.
- 5. At the same time educate and run social campaign showing the proper ways of reducing cyber-security threats, personal data breach** etc.

**Policy recommendations for the 4<sup>th</sup> Cluster: Distributed Generation and Storage Systems**

- 1. Review the coherence and completeness of private property regulations** and amend any loopholes that might pose a problem of market failures, particularly externalities. Land use regulations and urban or regional planning should be screened for potential undesirable impacts that might limit investments in grid or storage facilities.
- 2. Promote market-based instruments as a device for establishing necessary price signals and internalizing external effects.** Monitor whether relevant public policies towards energy sector do not distort competition nor decrease environmental effects that are expected from them. Example: consider a support scheme based on certificates that will incentivise energy savings made by end-users.
- 3. Run pilot programmes in order to establish the best practices regarding interoperability and stakeholders’ role in distributed systems.** Support those programmes with a body of empirical research, new databases obtained from decentralized sources like IoT and relevant set of performance indicators.
- 4. Educate key stakeholders and communities, showing possible technological and non-technological solutions and their impact.** Cooperate with business and NGO sector and assure that regional and local authorities possess sufficient skills & knowledge to be the change leader.





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For us, true sustainability also means an industry that's commercially viable, endlessly innovative, and highly competitive. We make this possible by helping Europe adopt pioneering new technologies, without risk or complexity. From mobility to construction – from renewable energy sources to smarter storage – our commercially-attractive technologies are the product of a trusted ecosystem for sustainable energy.

We've invested in more than 250 assets, 120 of which provide ROI with a forecasted revenue of €10-13 million. And we bring together more than 400 key players from across the energy value chain, from 18 different countries, and with indirect access to 150 million energy consumers. The result is the proven, landmark innovation you need to reduce energy costs, increase system performance, decrease GHG emissions, create jobs, and increase competitiveness.

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It's a reflection of our reputation for delivering practical innovation and, above all else, supporting the industry as it undergoes transformation for the future.



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# Appendices

# Appendix 1

## Summary of the general analytical framework

Appendix 1 contains description of the general analytical framework in the report as well as related tools and outcomes of performed analyses. It is important to emphasize that apart from dedicated survey, data from other sources was used in independent statistical and econometric analyses. While outcomes from the former largely constitutes our investment recommendations,

Table 17. Analytical framework for impact & investment attractiveness assessment

Step	Analysis	Tool	Outcome
1	Identification of key groups of technological and non-technological solutions	Desk research, interviews and consultations with experts	Synthetic map of innovative solutions in transport and heating. Subgroups of solutions to assess via survey (e.g. CNG refuelling infrastructure).
2	Gathering of target indicators related to: <ul style="list-style-type: none"><li>▪Smog reduction potential, based on expert assessment (e.g. decrease of PM10)</li><li>▪Potential market and technological attractiveness</li><li>▪Assessment of Technology Readiness Level, Consumer Readiness Level, Regulatory framework and reliance of public suppor</li></ul>	Survey among a panel of experts in heating and transport technologies	Target indicators for impact, market and technological and attractiveness
3	Construction of urban and regional data sample, using public source (Eurostat). Statistical analysis and estimation of panel econometric models in order to determine causal relations between smog, economic, social and other factors.	Statistical and econometric analysis, literature review	Econometric panel models of smog in European cities – evidence on dependencies between economic growth, smog and other variables. Secondary source for policy recommendations. Estimation of market size for several groups of technologies. It is a secondary source for investment recommendations.
4	Quantification of the impact on smog reduction as well as market and technological attractiveness estimation for solutions assessed in the survey. The Model uses normalised values for urban and regional variables. Important expert assumptions regards matching specific solutions (e.g. CNG refuelling infrastructure) with relevant scale and structural factors.	Quantitative model	Solutions with the highest potential impact on smog reduction and market and technological attractiveness. Primary source for investment recommendations.

Source: Analysis by Deloitte

## Dedicated survey

In order to assess the impact on emissions, and market attractiveness, a dedicated survey was performed. Survey was addressed to industry and academic experts in heating and transport technologies, who work in the European Union. Over 111 experts assessed technologies. Each participant could choose the technologies that they specialize in and evaluate them. On average, each technology was assessed by 5 experts. The experts assessed all three areas: impact on emissions, technological attractiveness and market attractiveness. **The result is 25 technologies in heating and 25 in transport that are presented in this report.**

## Data from public sources

Considering the nature of smog, the analysis is focused on urban and metropolitan areas. Due to data availability, geographical scope was limited to the urban areas in the EU-28. The following data sources were used:

- The primary data source for a scale and structural factors are the **City statistics** database the **Perception Survey results**,
- The secondary data source is the **Degree of Urbanisation** provided by the Eurostat the **Regional Social Progress Index**.

Data was collected for 33 indicators for cities and agglomerations in the EU-28. We decided to include only the data on cities<sup>368</sup> for which less than 30 percent of indicators were missing. It has led to the final sample of 67 cities<sup>369</sup> from all EU-28 countries, except for Croatia and Cyprus.

# Appendix 2

Appendix 2 contains detailed outcomes of our econometric study. Results of this assessment is subject to standard methodological limitations that are described in the literature or similar assessments. Thus, all the results should be interpreted with caution, in our case largely due to the imperfect data. Specifically, the major obstacles were short time-series and limited number of explanatory and control variables. In our opinion, these constraints might also contribute to mixed evidence on existence of EKC.

Table 18. Panel model estimation – determinants of annual average concentration of PM10 (Model 1)

Dependent variable	Independent variable	Model specification 1	Model specification 2	Model specification 3
Annual average concen-tration of PM <sub>10</sub> (µg/m³)	Constant	20.605 (p<0.001)	32.377 (p<0.001)	32.262 (p<0.001)
	GDP at current market price	0.000172015	0.000247 (p<0.1)	8.50408 <sup>-5</sup>
	Squared GDP at current market price	-3.92339 <sup>-10</sup>	-5.53846 <sup>-10</sup>	2.56007 <sup>-11</sup>
	Heating degreedays	X	0.000673669	0.000794013
	Implicit tax rate on energy	X	-0.0208316	-0.00834432
	Share of renewable energy in fuel consumption of transport	X	0.121561	0.128029
	Share of renewable energy in gross final energy consumption	X	-0.672 (p<0.001)	-0.735 (p<0.001)
	Perception of the problem of air pollution	X	X	-0.735 (p<0.001)

Source:Deloitte's analysis. Sample: 67 European cities



Table 19. **Panel model estimation – determinants of annual average concentration of NO<sub>2</sub> (Model 2)**

Dependent variable	Independent variable	Model specification 1	Model specification 2	Model specification 3
Annual average concentration of NO <sub>2</sub> (µg/m <sup>3</sup> )	Constant	30.389 (p<0.001)	36.982 (p<0.001)	36.452 (p<0.001)
	GDP at current market price	−0.000100440	−5.29807 <sup>−5</sup>	−3.01392 <sup>−5</sup>
	Squared GDP at current market price	4.52876 <sup>−10</sup>	3.77087 <sup>−10</sup>	−1.23766
	Heating degreedays	X	0.00103768	0.000726472
	Implicit tax rate on energy	X	−0.0211032	−0.00863182
	Share of renewable energy in fuel consumption of transport	X	0.135876	0.219122
	Share of renewable energy in gross final energy consumption	X	−0.557186	−0.365048
	Perception of the problem of air pollution	X	X	−0.0899165

Source: Deloitte’s analysis. Sample: 67 European cities

Table 20. **Panel model estimation – determinants of Number of days when PM10 concentration exceed 50µg/m3 (Model 3)**

Dependent variable	Independent variable	Model specification 1	Model specification 2	Model specification 3
Number of days when PM10 concentration exceed 50µg/m <sup>3</sup>	Constant	17.9076	32.7182 (p<0.1)	31.5632
	GDP at current market price	0.000315172	0.000553819	0.000232367
	Squared GDP at current market price	−5.23007 <sup>−10</sup>	−1.10879 <sup>−9</sup>	1.5007 <sup>−9</sup>
	Heating degreedays	X	−0.00106081	0.00122798
	Implicit tax rate on energy	X	0.0398228	0.0321205
	Share of renewable energy in fuel consumption of transport	X	0.643921	0.444872
	Share of renewable energy in gross final energy consumption	X	−0.672 (p<0.001)	−0.735 (p<0.001)
	Perception of the problem of air pollution	X	X	0.116968

Source: Deloitte’s analysis. Sample: 67 European cities

Table 21. **Sample of European cities used for the econometric panel models and assessment of market potential**

Code	City	Country	Code (cont.)	City (cont.)	Country (cont.)
BE001C1	Bruxelles	Belgium	IT004C1	Torino	Italy
BE002C1	Antwerpen	Belgium	IT005C1	Palermo	Italy
BE005C1	Liège	Belgium	IT009C1	Bologna	Italy
BG001C1	Sofia	Bulgaria	IT012C1	Verona	Italy
BG004C1	Burgas	Bulgaria	LV001C1	Riga	Latvia
CZ001C1	Praha	Czech Republic	LT001C1	Vilnius	Lithuania
CZ003C1	Ostrava	Czech Republic	LU001C1	Luxembourg	Luxembourg
DK001C1	København	Denmark	HU001C1	Budapest	Hungary
DK004C2	Aalborg	Denmark	HU002C1	Miskolc	Hungary
DE001C1	Berlin	Germany	MT001C1	Valletta	Malta
DE002C1	Hamburg	Germany	NL002C1	Amsterdam	Netherlands
DE003C1	München	Germany	NL003C1	Rotterdam	Netherlands
DE006C1	Essen	Germany	AT001C1	Wien	Austria
DE008C1	Leipzig	Germany	PL001C1	Warszawa	Poland
DE010C1	Dortmund	Germany	PL003C1	Kraków	Poland
DE029C1	Frankfurt (Oder)	Germany	PL006C1	Gdansk	Poland
DE043C1	Rostock	Germany	PL011C1	Białystok	Poland
DE044C1	Kaiserslautern	Germany	PT001C1	Lisboa	Portugal
EE001C1	Tallinn	Estonia	PT003C1	Braga	Portugal
IE001C1	Dublin	Ireland	RO001C1	Bucuresti	Romania
EL001C1	Athina	Greece	RO002C1	Cluj-Napoca	Romania
EL004C1	Irakleio	Greece	RO011C1	Piatra Neamt	Romania
ES001C1	Madrid	Spain	SI001C1	Ljubljana	Slovenia
ES002C1	Barcelona	Spain	SK001C1	Bratislava	Slovakia
ES006C1	Málaga	Spain	SK002C1	Kosice	Slovakia
ES013C1	Oviedo	Spain	FI001C2	Helsinki	Finland
FR001C1	Paris	France	SE001C1	Stockholm	Sweden
FR006C2	Strasbourg	France	SE003C1	Malmö	Sweden
FR007C1	Bordeaux	France	UK004C1	Glasgow	Great Britain
FR009C1	Lille	France	UK008C1	Manchester	Great Britain
FR013C2	Rennes	France	UK009C1	Cardiff	Great Britain
FR203C1	Marseille	France	UK012C1	Belfast	Great Britain
IT001C1	Roma	Italy	UK013C1	Newcastle	Great Britain

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