IT IS IN THE AIR

Exploring cleaner air pathways for Zabrze

Printing paid by the Swedish-Polish Sustainable Energy Platform. This project is part of the MSc. Environmental Management and Policy at International Institute for Industrial Environmental Economics, Lund University. Supported by the Swedish-Polish Sustainable Energy Platform, the International Institute for Industrial Environmental Economics, Lund University, and the City of Zabrze.

IT IS IN THE AIR: Exploring cleaner air pathways for Zabrze

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This publication should be cited as:

International Institute for Industrial Environmental Economics [IIIEE] (2017). It is in the air: Exploring cleaner air pathways for Zabrze. Lund: IIIEE

ISBN: 978-91-87357-29-9

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ACKNOWLEDGEMENTS

Our student team would like to express the deepest gratitude to the mayor of Zabrze Małgorzata Mańka – Szulik, who kindly invited us to conduct the project on such an interesting topic. This report would not see the light of day without the continuous assistance of the municipality of Zabrze and its representative especially Agnieszka Jama, Zbigniew Rau, Ewa Pawłowska and Jaroslaw Gontek.

With their support it was possible to organize very insightful and informative meeting with other city departments as the Ecology, Urban Planning, Project Realization and Strategy Department. A special thanks we would like to say to the Institute of Environmental Engineering (Polish Academy of Sciences) and its dedicated professionals Krzysztof Klejnowski and Adam Łukasik.

Very meaningful contribution was made by the industry representatives, especially by solar companies of Pawel Górniok (Ekolenergia SP), Lesław Kordys (RAD-Instal), district heating company chaired by Lesław Złotorowicz and finally by Aleksander Sobolewski, the Director of the Institute for Chemical Processing of Coal. Very inspiring tune we got from dedicated NGO representatives, Kamila Knap, Magdalena Kozlowska and Patryk Białas.

Our thanks and appreciations also go to our caring university supervisor Mikael Backman and organized fruitful meetings on best practices from Sweden with Adam Kristensson (Lund University) and Mårten Spanne (Environmental Engineer Miljöförvaltningen).

Without knowledge of all of you, expertise and willingness to share it with us it would not be possible to shape this report in the best possible way. We perceive this project as a great learning opportunity and a big milestone in our career development facilitated by our Alma Mater, Lund University.

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EXECUTIVE SUMMARY

Air pollution is one of the most complex environmental and social problems especially for urban areas. However, cities usually have limited possibilities to influence the situation, given the transboundary nature of most of the pollutants and limited regulatory power.

Air Pollution is a burning problem in Zabrze

On the European scene, Poland is one of the countries that suffers the most severe consequences of air pollution, and on a local level Zabrze is one of cities with the highest air pollution in Europe. The situation is especially critical in the winter season.

Through research and numerous interviews before and during the fieldwork, it was identified that the main contributor to air pollution in Zabrze is residential heating, particularly, coal-fired stoves and furnaces. Most of the buildings in Zabrze city center are very old, with very low energy efficiency. Similarly, the heating equipment are outdated and inefficient.

Bearing in mind the complexity of the issue and, at the same time, recognising residential heating as of utmost priority, the report focuses on the technical solutions for the heating sector specifically and the enabling measures for air pollution in general.

Coal-based or Cleaner heating?

We envision two potential directions where Zabrze could go in modernizing its heating system. The description of these directions is given along with their implications for urban air quality and the city. Each of them presents a certain twenty years vision. A baseline scenario, mostly coal-based, and an alternative scenario, that relies on cleaner heating sources such as renewables, were developed and compared in terms of emission reduction potential and costs.

A cleaner and cheaper alternative exists for Zabrze

Alternative scenario achieves 91% reduction in particulate matter compared to today's level, while baseline scenario leads to a 75% reduction.

It is important to consider not only initial costs, but the savings over the lifetime of the technology. Even though the investment costs for the alternative scenario is higher than the baseline scenario, the yearly operating cost are much lower. When operating costs over 20 years are taken into account, the alternative scenario is 15% cheaper than the baseline scenario.

Moreover, there are several benefits which were not part of the cost calculations, such as health benefits, employment, recreational value, property value, and avoided technological lock-in to finite fuels.

Enabling measures are crucial for dealing with the situation

Enabling measures, such as data management, strategic incorporation, enhanced collaboration and nature based solutions, do not result in a drastic pollution reduction by themselves, but they rather act as facilitators of the transition. Monitoring, emission inventory building and modelling are all necessary steps in order to develop a comprehensive urban air quality strategy. Since air pollution situation is so critical in Zabrze, it should be better incorporated into the City Development Strategy too.

Higher awareness among the citizens on the causes and negative effects of air pollution will result in faster deployment of cleaner heating systems, and stronger public support for the measures. Air pollution is a complex problem which necessitates collaboration of all the stakeholders in various areas ranging from data collection to public awareness, from technological transition to financing.

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INTRODUCTION

THE ISSUE OF AIR POLLUTION

Air pollution is one of the most complex environmental and social issues that the humanity faces. It is a systemic issue characterized by a variety of types, sources, effects and inter linkages. Adding a layer of complexity, many pollutants has the ability to travel long distances, which calls for coordinated efforts and brings about the importance of multistakeholder cooperation for dealing with the problem.

There are a number of sources and associated pollutants contributing to the problem. It should be said that the main pollutants are categorized into primary and secondary air pollutants. Primary pollutants are emitted directly from sources. Several of them, then, interact together, and with other atmospheric components, to form secondary pollutants. One such example is sulfur dioxide that, once released into the air, forms particulate matter. Understanding this non-linear relationship is crucial for any intervention: targeting primary pollutants can bring side benefits in form of reduction of secondary pollutants.

Smog is a type of air pollution. Figure 2 shows how different types of smog are formed (Figure 2).

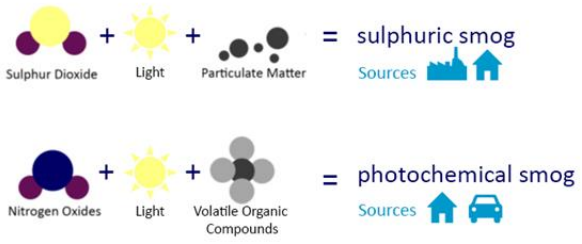


Figure 1 - Two main types of smog

To successfully fight the smog, all pollutants involved have to be addressed at once. Otherwise, the effectiveness will be significantly reduced.

Air pollution causes a variety of environmental problems [1]. It negatively affects the Earth's ecosystems, including forests, water bodies, soils and wildlife.

Furthermore, contaminated air poses a major risk to human health as also described on Figure 2.

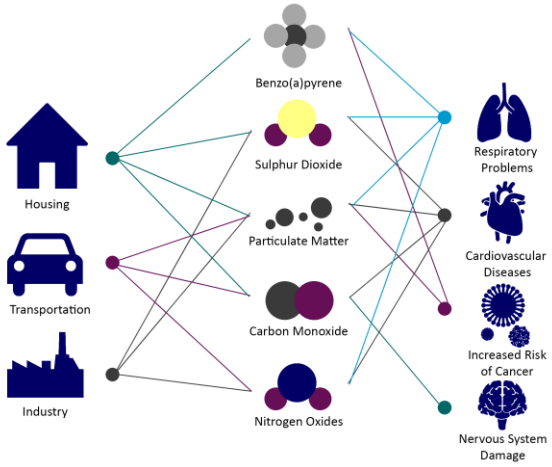


Figure 2 - Main sources, types and health effects of air pollution

Estimates from the World Health Organization show that, globally, around 7 million annual premature deaths can be linked to air pollution [2]. In Europe alone, air pollution is responsible for half a million premature deaths each year [3]. When it comes to Poland this number stands at 43 000 [4].

«Globally, 7 million annual premature deaths can be linked to air pollution»
— WHO

Apart from these tangible and well-researched **health risks**, an increasing number of studies links air pollution to other, rather surprising aspects of wellbeing. Bad air quality is said to affect individual happiness, as well as increase the rate of depression [5]. Besides, air pollution, particularly, from traffic, is linked to skin aging [6].

Health effects represent a heavy burden for the **economy**. Increased costs for hospitals, reduced productivity, increased frequency of sick leaves,

and most importantly, increased mortality rate, all contribute to the overall societal bill. An OECD report on the economic effects of air pollution suggests that the negative health effects of air pollution directly influences the labour productivity, which in return affects the wages and thus the savings negatively, causing reduced macroeconomic performance [1]. The report projects that, the combined effect of direct productivity loss and the costs for the health system can account for up to 4% of the overall GDP.

Air pollution also has negative effects on **agricultural yield** and thus on the food security. Research estimates that the crop yield loss due to air pollution can amount to 5% in the U.S. [1]. Reduced yield in agriculture will result in higher food prices, which mostly harms the economies of lower income citizens. Moreover, it undermines the economic independence by increasing the need to import agricultural products.

«Air pollution reduces property values by damaging the façades and decreasing the demand for property»

Furthermore, air pollution has adverse effects on the **property values**, both through directly damaging the façades of the buildings and through reduced demand for property in the areas where air is polluted. A research conducted in the U.S. shows that significant economic gains were achieved during the 1970s and 1980s in the housing market after the Clean Air Act was put into effect and air pollution levels were reduced [7]. Researchers calculated that, the economic benefits of the reduction of air pollution through the Clean Air Act to American homeowners aggregated to $50 billion.

Figure 3 - Negative effects of air pollution

Air pollution has negative effects on **tourism**. Reduced visibility and damages to cultural heritage caused by some of the pollutants can significantly undermine the attractiveness of the destination. Moreover, some visitors start to include air pollution considerations in their choice of vacation spot and avoid highly polluted places [8]. Needless to say, it translates into significant economic losses for every city that sees tourism development as a significant part of their economy.

POSITIVE SIDE EFFECTS?

- Suspended air particles in the air filter out certain colors of the sky, meaning that red and orange can be seen more vividly. This can result in beautiful sunsets, but only up to a certain point, when air pollution is so thick it blocks all colors and the sunset cannot be seen at all.
- Particulate pollution can slow down global warming due to the so-called dimming effect. They absorb energy from sun and reflect sunlight back to space.

...Unfortunately, there will be less people to enjoy these side effects if no action is taken.

URBAN AIR POLLUTION

Due to high population density and more developed infrastructure, cities usually experience higher levels of pollution than other places. There is no one-fits-all solution for urban air pollution, as there are large differences among the sources of air pollution, geographical, political and economic conditions and cultural context in different cities. But there is one thing all cities have in common: the urgent need to act, fueled by demands from the citizens, national and regional governments and supranational institutions.

The areas of cities' activities to tackle the air pollution usually include [9]:

1. Emission inventory, measurement and modelling
2. Air pollution management
3. Public information

Emission inventory, measurement and modelling is important in order to get a clearer picture of the current situation and to track the changes in air quality over time. Air pollution management aims at improving the air quality through administrative measures, such as introduction of low emission zones, fuel conversion in domestic heating, expansion of district heating network, careful urban planning. Public information is needed both to communicate the changes and to enhance other efforts by creating public awareness, such as in the case of promoting public transport.

However, cities usually have limited possibilities for influence, given the transboundary nature of most of pollutants and limited regulatory power of local authorities. Many of the most efficient measures require a certain degree of changes in national or regional legislation, such as vehicle fuel requirements and bans or industry emission standards.

Conceptually, urban air pollution concentrations for particulate matter can be described by Figure 3.

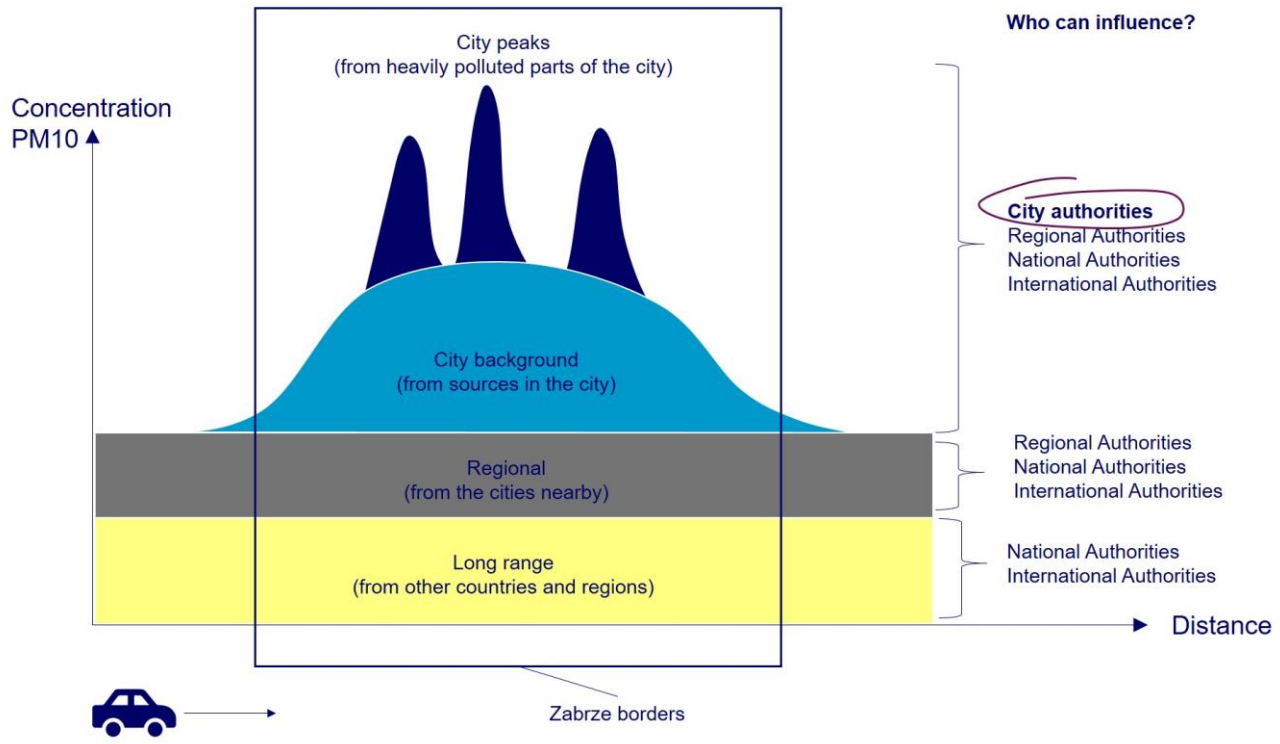


Figure 4 - Transboundary air pollution and air pollution layers in the city

There are several levels of pollution contributing to the overall concentration in the city. Entering the city one can feel different concentrations depending how close it is to the city peaks. The last layer is city peaks - pollution concentration on certain heavily polluted streets, e.g. those located close to highways, or within proximity of polluting industries.

Tackling city peaks and city background levels is equally important. Higher concentrations observed in peak areas are more toxic, however, they affect a smaller number of people under a shorter timeframe. In the meanwhile, the background level, while lower than peak level, is characterized by a broader exposure in terms of time and number of people affected. It is worth noting that some gaseous pollutants are more local, therefore, the regional and long-range levels will contribute less to the overall concentrations.

LEGISLATION

Air pollution and different kind of pollutants has been regulated by law on international level for a longer time. The current regulation on air pollution in Europe is the EU Directive 2008/50/E, and several daughter directives related to this directive. The directive establishes objectives with regards to the limit values of pollutants, data requirements assessing the ambient air quality in member states, it further, combats pollution, ensure data are available to the public, maintaining air quality where it is good and increase cooperation between states. Furthermore, The Directive sets out procedures and directions on sampling points, their number and location.

EU member states are obliged to follow the requirements set by the EU Directive 2008/50/EC and transpose it into the national legislation. In case of Poland, it was transposed into the act on the "System to Manage the Emissions of Greenhouse Gases and Other Substances" in 2009. Poland has also recently adopted the so called anti-smog law, signed by the President in 2015. The law introduces the possibility to implement local regulatory measures to improve environmental and human health, when it comes to air quality and noise.

Silesian region is catching up with its regional efforts to improve the air quality. The so-called Anti-smog resolution has recently been adopted in April 2017. According to the resolution, from 1st of September, combustion of solid waste is no longer permitted. Moreover it will not be allowed to burn the lignite and damp wood in the furnaces. Inefficient heating equipment is also subjected to exchange. By 2028 low standard furnaces should be phased out and by 1st of January 2022 all the stoves should be of the 5th class of efficiency [10].

CURRENT SITUATION

AIR POLLUTION IN ZABRZE

On the European scene Poland is one of the countries that suffers the most severe consequences of air pollution. In 2016, Poland was home to 33 out of Europe's 50 most polluted cities. Poland finds itself in chronic breach of the EU limit values. This brings about attention from the EU, with European Commission warning the country that legal action will be taken unless Poland complies with EU legislation [11].

On a local level, together with other cities situated closeby, Zabrze is a frequent visitor on the lists of Top 10 most polluted cities in Europe. In 2016, it exceeded the EU limits with regards to PM10 and benzo(a)pyrene as it can be seen on Table 1 [12]. According to the official information available for the region on the air quality during 5 years starting 2010, almost all the cities in the Silesian Voivodship exceeded the permit for 24 hour concentration of PM10 on average 3 times. With regard to other pollutants, such NO_x and SO_x, the concentration is approaching the limits. Unfortunately, the city of Zabrze is not an exception. The situation is critical especially in the winter season. Current projections of PM10 concentrations for year 2020 paint a gloomy picture for the region.

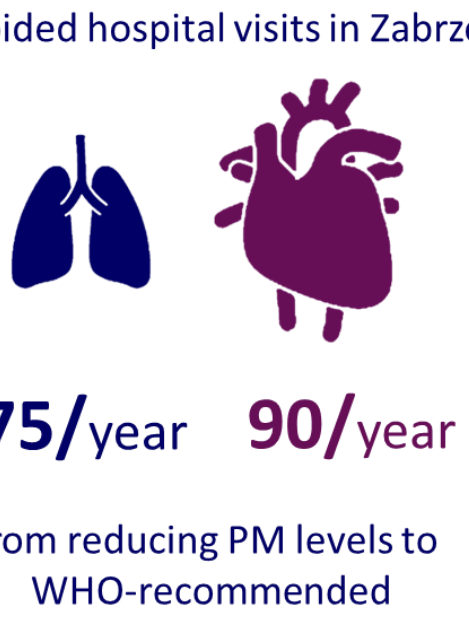
Table 1 - Levels of air pollution in Zabrze

Pollutant	Zabrze	EU Directive
PM10 Annual mean; Exceedances	46 g/m³; 93	40 g/m³; 25
NO_x Annual mean	36 g/m³	30 g/m³
SO_2	Not comparable	
CO	Not comparable	
BaP Annual mean	9 ng/m³	1 ng/m³
O_3	Not comparable	

NEGATIVE EFFECTS

It is estimated that 40 deaths can be avoided annually in Zabrze, in addition to 90 visits to hospitals due to respiratory diseases and 75 hospital visits due to cardiac diseases, if the PM10 concentration were reduced to the levels recommended by the WTO.

On average, a 5 µg/m3 decrease in annual mean concentration is said to be associated with 4.9 avoided deaths in Zabrze [13]. Many more hospital visits can be avoided from reducing the



concentration. In fact, Zabrze' own Center for Heart Diseases has recently confirmed that air pollution had a very negative effect on admitted patients with heart problems.

Translating health effects into economic losses, a brief estimation of annual costs from excessive concentrations of NO_2 and PM to Zabrze municipality returns the result of PLN 116 million, a figure to be considered as the absolutely lowest threshold.

116 mln zl/year

unpaid health bill

Even more severe health consequences stem from indoor air pollution, due to higher concentration and generally longer exposure time than outdoor air pollution. While not a focus of this report, it is important to mention that some of the same pollutants that are affecting outdoor air quality are likely to be present indoors, particularly, SO_2 and B(a)P, associated with coal-fired heating. Thus, targeting them can bring additional benefits not considered in this report.

Many of the non-health related negative effects described in the previous chapter could be observed in Zabrze during study visits. For example, an ongoing research project undertaken by the Institute of Environmental Engineering, shows that air pollution accumulated in Zabrze over years has a detrimental effect on local soils. In addition, façades of many buildings were carrying black crust from decades of coal soot accumulation.

INTEGRATION OF SOCIETAL COSTS INTO DECISION MAKING

Cost Benefit Analysis allows to take into account societal costs and benefits of alternative projects when making investment decisions. It is a tool increasingly used in policy making and public project management.

A CBA was performed in Helsinki on a green roofs project. Apart from the investment and operational costs associated with installing and maintaining the roofs, their contribution to reduction of energy costs, health benefits, contribution to storm water management and aesthetic value were included as benefits. Thus, a total benefit for society as a whole outweighed the costs and the project was implemented. If, instead, only direct revenues were considered, the project would have been rejected.

SOURCES

«The main source of air pollution in Zabrze is coal-fired residential heating»

During numerous preparatory interviews and onsite visits before the field work in Zabrze itself, it was pointed out that the main sector

responsible for air pollution in Zabrze is residential heating, particularly, coal-fired stoves and furnaces.

Figure 4 describes the main sources of pollutants for the whole Silesian region. For all of the pollutants presented, except NO2, the heating sector is the main contributor, with transboundary pollution following the lead. It must be noted that the data presented in the graph is averaged over a year. It can thus be predicted that the share of the heating sector in the total mix is even higher during winter.

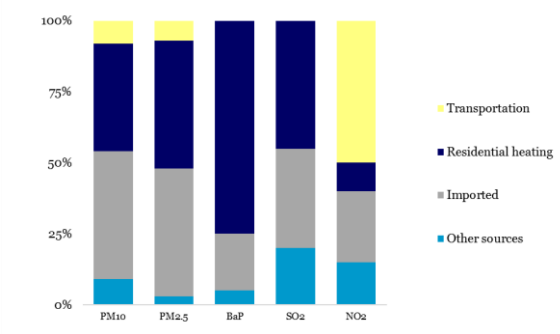


Figure 5 - Sources of air pollution in Silesian Region

It is difficult to measure how the situation in Zabrze differs from the regional picture, due to high city density, and lack of emission inventory. Most likely, it is a fairly similar mix, as pointed out by the city representatives during the visits.

Since many cities across Europe have come a longer way in transforming their residential energy systems, transportation often becomes the main sector to target for reduction of air emissions. This gives a misleading idea that the main source of air emissions is, unequivocally, transport. Same applies to smog, which is often associated exclusively with vehicles.

Coming back to Zabrze, transportation plays a marginal role in the overall air pollution picture for all the pollutants, except NO_2. However, the issue should not be underestimated. Zabrze vehicle fleet is old and inefficient: the share of cars older than 10 years is 77%, 22% of lorries are older than 30 years, almost a third of buses are older than 10 years [12]. However, fuel standards for vehicles are set on the national level, making traffic management the main area of intervention on the city level. The main subject of targeted city effort is often heavy trucks, due to their higher average age.

SCOPE

Having been given the broad task to look at air pollution in Zabrze, it was necessary to narrow the scope down to arrive at tangible results. As agreed with the city representatives, the report is mostly concerned with outdoor air pollution, while recognising and emphasizing the links between indoor and outdoor pollution and the importance of indoor air quality for human health. Moreover, while looking at all the main pollutant types laid out in the European Air Quality Directive, the report focuses at reductions in those pollutants for which the local situation is most critical. Last but not least, given last year's report focus on transportation and the moderate contribution of the sector to air pollution in Zabrze in general, the sector falls out of scope of our report. Instead, one important focus area of the report is the heating sector, acknowledged by all the interviewees as the main contributor to the problem.

REINTRODUCING GREEN WAVE FOR ZABRZE

A robust transportation sector strategy for Zabrze was developed last year by a group of students from IIIEE.

It included a description of co-benefits from sector decarbonisation in form of reduction in air pollution.

RESIDENTIAL HEATING IN ZABRZE

Heating system in Zabrze is based on a combination of district heating, coal fired furnaces and natural gas boilers. With data from the Low

47 000 households living in apartments

23 000 households living in detached houses

Emission Plan of Zabrze and data received from the municipality officials, it was possible to shape a complete picture of the city housing stock [14].

Although the specific data on average age of the total building stock in Zabrze is missing, according to the Institute of Environmental Economics in Cracow (2014), 72% of the single family buildings in Poland have low or very low level of thermal insulation [15].

Most of the buildings in Zabrze city center are very old, many of them having been built before the World War II. For example, 2.261 households which are managed by Terma-Dom Sp. z o.o. have the average age of 93 years. These old buildings are often poorly insulated, which causes high fuel consumption for heating.

Around 21 000 of the households are connected to the district heating network. Fortum Zabrze S.A. is the main producer of the heat, where the main fuel is coal. The company is constructing a new modern boiler which is due 2018 and will allow the company to use REF and biomass as fuel, along with coal. ZPEC Sp. z o.o. is the district heating distribution company, owned by the Municipality of Zabrze. Apart from residential buildings, the company also supplies heat to many public buildings, such as city hall, schools and hospitals. ZPEC is in the process of securing funds for network expansion. The project is expected to increase the share of district heating among multi-story buildings from 40% to 60%, which corresponds to approximately 7000 additional households joining the system.

Approximately 29 000 households use coal for heating, mostly burned in old, inefficient furnaces. The coal sales are not regulated and thus there is no control over the quality of coal being sold. It is a common practice, especially among lower income households, to burn very low quality coal, or even waste, which was also observed during the study visit.

Around 20 000 households use natural gas for heating. Natural gas network is well developed and covers most of the city. Figure 5 summarizes the heating systems of Zabrze households according to fuel and household type.

Figure 6 - Current heating system in Zabrze by number of households and types of homes

The city is running a financial support program since 2007, PONE - KAWKA (Low Level Emission Reduction Program) to incentivize the thermal modernization and renovation of the building stock. Within this framework, change of coal/gas boilers to efficient models, installations of solar water heating and photovoltaics, and investments related to energy efficiency of the buildings are supported with up to 80% of the cost. Between 2007 and 2017, around 2000 households living in detached buildings were thermo-modernized within the program. Considering the total number of households, the thermo-modernization achieved through the support program in 10 years is not enough to reduce the low-stack emissions significantly. According to the municipality officials, the main reason for the low pace of thermo-modernization is the long waiting times for funding. Regional administration is where relevant fund is distributed from, upon the applications of municipalities. Even though the

Municipality of Zabrze sometimes pays out the support to applicant citizens before receiving funding from the regional administration, the waiting period for the support is currently around 2-3 years.

APPROACH

Bearing in mind the complexity of the issue and, at the same time, recognising residential heating as of utmost priority, the report focuses on technical solutions for the heating sector specifically and the enabling measures for air pollution in general.

First, we envision two potential directions where the city could go in developing its heating system and discussed their implications for urban air quality and the city in general. A baseline scenario and an alternative scenario that relies on cleaner heating sources were developed and compared in terms of costs and emission reduction potentials.

As a second step, we describe a toolbox of measures (enablers) that, in themselves, do not result in a drastic pollution reduction, but rather act as facilitators. They consist of enhanced collaboration, awareness building, strategic recommendations, data management and nature based solutions.

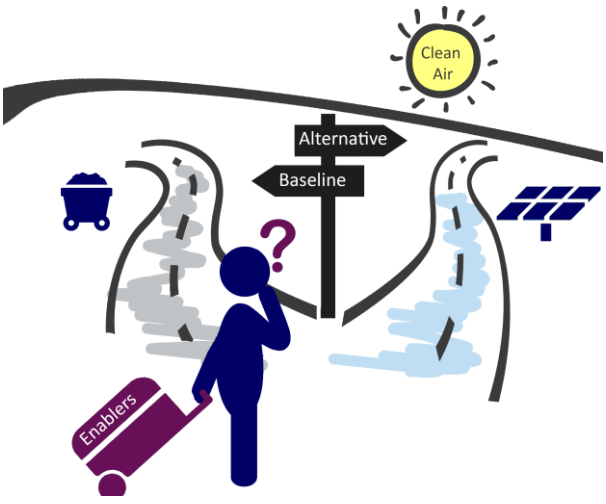


Figure 7 - Zabrze at the crossroads

FUTURE OF HEATING IN ZABRZE

INTRODUCTION TO SCENARIOS

Two alternative scenarios for Zabrze future will be presented. Each of them presents a certain twenty years vision for the heating systems in Zabrze, ranging from mostly coal-based systems in the baseline scenario to systems incorporating renewable sources in the alternative scenario. For each of the scenario, a separate mix of heating solutions was developed for the housing stock. At the end of the section, the paths will be compared based on costs, co-benefits and other factors.

Differences:

The baseline scenario was developed based on our interpretation of the direction that the city of Zabrze intends to go. During the interviews conducted with officials from various departments of the Municipality, and the interviews with other stakeholders, the certain possible solutions were voiced significantly more often than others. These possible solutions ranged from electrostatic precipitators to cleaner coal, however, all of them had one thing in common: imagination of a future where burning coal continues to be the main source of heating in Zabrze, and where the negative effects are tried to be minimized mostly through more efficient furnaces, end-of-pipe solutions and higher quality coal.

The alternative scenario assumes a significant reduction of coal based heating systems for single family houses, and introduction of renewables. It approaches air pollution problem from a prevention perspective and aims to illustrate a heating system that is not entirely based on coal. Pollution prevention implies replacing the origin of the pollution (coal) with cleaner alternatives, like solar panels, district heating and gas. However, even this scenario recognizes that a complete change is not feasible, leaving some marginal space for coal.

Similarities:

Any changes in the heating system should be preceded by extensive energy efficiency efforts in order to avoid operational losses. Thermal insulation of houses is one of the cheapest ways to fight low stack air pollution. Reducing energy intensity of houses means a significant reduction in the annual heat demand, which correlates with the annual concentrations in, particularly, SO_2, NOx and B(a)P. Therefore, current efforts of the Municipality to increase energy efficiency of the housing stock form an integral part of both scenarios.

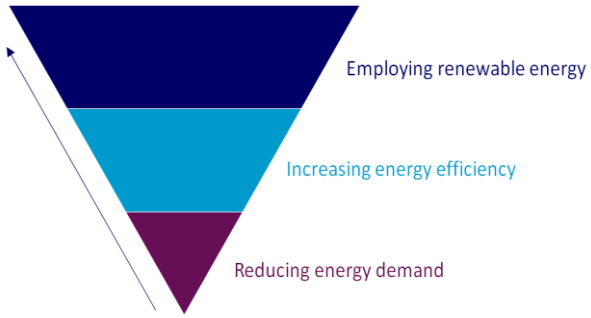


Figure 8 - Priorities for energy interventions

District heating has a central role in the heating system in Zabrze, and in the efforts in the prevention of air pollution. The construction of a new boiler for the district heating plant and the expansion project of the network are important steps towards cleaner air for Zabrze. Thus, district heating is included in both scenarios to the same degree.

For each of the scenarios, the existing housing stock was split between several heating alternatives, bearing in mind that solutions for single family houses are generally different than solutions for multi-family houses. The investment costs to transform the system in each case were then calculated, including change of furnaces, heating and other installations. In addition, operating costs (energy bills) were estimated based on the current energy prices for different carriers and the heat demand, correcting for energy and fuel efficiency. The scenarios were then compared based on applied technologies, investment and operational costs, cost effectiveness in air pollution reduction and finally indirect costs and benefits. Besides, the technologies employed in each of the scenario were discussed, as well as their viability in light of the current trends in the energy market. The assumptions and their likely influence on the results were outlined throughout the report.

Table 2 - End of pipe approach vs. Preventative approach

End of pipe	Prevention
Short-term solution	Long-term solution
Dependent on additional technologies for emission reduction	Not dependent on additional technologies for emission reduction
Treat existing emissions and not the origin	Treats the origin of the pollutants
Additional investment and running costs	Creates opportunities for savings
Limited pollution reduction	Significant reduction in emissions
Costs related to health still high	Opportunities for job creation
	Economically beneficial in long term

BASELINE SCENARIO

The baseline scenario assumes that the current efforts in practice, such as the support of energy efficiency and thermo-modernization, will continue, and energy projects under development will be operational as planned, such as the district heating expansion project. Moreover, the scenario envisions significant reduction in the number of multistory buildings using coal, most of which will be covered by the district heating network expansion, with some switching to natural gas as fuel for heating.

The scenario (Figure 8) assumes that all the old coal fired furnaces will be replaced by new furnaces, with high efficiency levels in compliance with the EU regulation. It is also suggests that most of the coal burning households will be using high quality "cleaner coal", equivalent in quality and cost to the one developed by the Institute for Chemical Processing of Coal in Zabrze, which was visited during the study trip.

Figure 9 - Residential heating system in Zabrze under the baseline scenario, by households

To illustrate the effect of possible end-of-pipe solutions, around 25% of the detached households are envisioned to be equipped with household size electrostatic precipitators, equivalent in efficiency and cost to the one developed by the Department of Chemical Engineering and Process Design of the Faculty of Chemistry at the Silesian University of Technology, which was also visited during the study trip.

The running costs for each fuel type and the investment costs for district heating expansion project, installation of condensing natural gas boilers, replacement of coal furnaces, installation of electrostatic precipitators and R&D costs for "clean coal" are included in the calculations. The cost calculations are mostly based on the equipment and fuel prices in and around Zabrze, obtained in various occasions during the study trip.

The thermal modernization of the building stock in Zabrze requires substantial amount of funding. Most of the buildings which are in urgent need for efficiency investments and furnace replacements are occupied by lower income households, who do not have the financial means to cover the necessary investments. Moreover, many of the households living in the multi-story buildings are renters and the owners of the buildings either do not possess the financial resources nor financial incentive to invest in these projects since the tenants cannot afford any increase of rent. The support scheme of the Municipality receives the funding from the regional administration, which is quite limited and the overall process takes very long time. Thus, there is a long waiting list for the support scheme, which is around 2-3 years according to city officials.

ALTERNATIVE SCENARIO — GREENER HEATING SYSTEM

Overall the alternative scenario envisions a minimization of coal based heating system for Zabrze that is composed of a combination of cleaner solutions.

For the households living in multi-story buildings, it is assumed that the natural gas use will be increased by 20% (3000 additional households) compared to the baseline pathway. The households using district heating will stay the same as the baseline given the technical and economic limitations of expanding the network communicated to us during the visits.

Figure 10 - Residential heating system in Zabrze under the alternative scenario, by households

The biggest difference of the alternative pathway from the baseline pathway is in the heating solutions for the single and double family households living in detached buildings. In designing these solutions, we kept several factors in mind. The new heating sources had to be drastically cleaner, locally sourced as much as possible, appropriate given the local conditions, and be in line with existing global trends. The scenario envisions that majority of the detached building households with coal based heating systems will switch to a cleaner heating solutions. The solution is based on the combination of air-to-water heat pumps either powered by photovoltaic panels or assisted by solar water heating, and natural gas boilers, which are also assisted by solar water heating.

For better comprehension the system is presented on Figure 10.

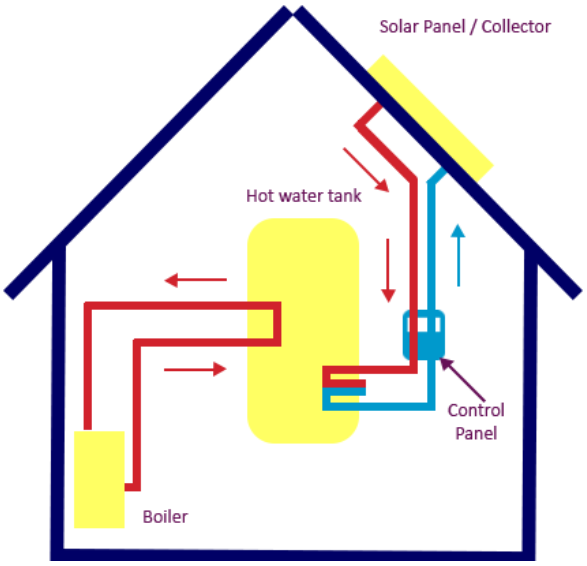


Figure 11 - Solar aided gas system for single family households

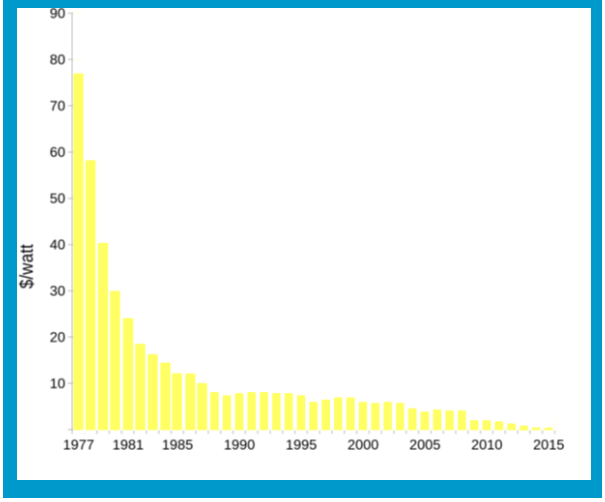
For the alternative pathway, potential electricity production by PV are calculated through the online tool of Photovoltaic Geographical Information System (PVGIS), provided by the European Commission [17]. Based on the calculations, a PV system which can cover more than 100% of the energy consumption of an air-to-water heat pump is envisioned to be installed at each house (see appendix for technical details). Currently, Poland has a net metering policy for solar electricity production, which offers 80% accounting for electricity fed into the grid. Practically, this enables the PV owners to use 80% of the energy they produced during the sunny hours without cost during the evenings. The existing net-metering policy is assumed to continue throughout the scenario, however no further possible support scheme is included.

SOLAR IN POLAND AND THE WORLD

Solar industry has been experiencing dramatic cost reductions over the years. According to International Renewable Energy Agency, since 2009 average costs for electricity produced by solar photovoltaics has fallen 80%, and until 2025 it can fall an additional 59% [18]. The cost reduction results in higher degrees of adoption, which in return can result in further cost reductions.

A heating system based on renewable sources is achievable for Zabrze, as the city has favourable solar energy potential. Zabrze is located in the Southern part of Poland, where average solar radiation is around 1200 kwh/m^2, reaching up to 1300 kwh/m2. This potential is similar to Germany, which has the second largest installed solar PV capacity in the world, after China.

Below is the price history of silicone PV cells over the last decades.



COMPARISON OF THE SCENARIOS

After the potential scenarios have been introduced and thoroughly described, it is high time to compare them in order to be able to choose a better alternative.

TECHNOLOGICAL ANALYSIS

Analysis of the utilized technologies for the scenario is the first step of the comparative chain. The advantages and disadvantages for various technologies constituting each of the scenarios are presented in the table in the Appendix, including the main heating system components[1].

EMISSION COMPARISON

The next step of the comparison is to contrast the scenario with each other against their emission reduction potential.

As demonstrated, both scenarios result in a certain degree of reduction of particulate matters. However only the alternative scenario can be considered as emission neutral.

Keeping in mind that the housing sector is only one, important as it is, piece of a puzzle, there remains a certain degree of uncertainty over whether a 75% reduction is enough to have a significant effect on air quality.

COST COMPARISON

Cost comparison is carried out in order to see the financial feasibility of the scenarios with a long-term perspective.

The overall societal cost of the two pathways entails two basic components: the cost of investment, borne partly by the municipality through subsidies and partly by the residents through co-financing; and operating costs, consisting of energy bills, borne by the residents. The total cost, then, is the sum of all these costs, corrected for the change in the value of money over time.

For baseline scenario, the total investment cost for transforming the heating system equals PLN 344 million. For the alternative scenario, the investment cost is 40% higher, at PLN 482 million.

INNOVATIVE THIRD PARTY FINANCING FOR SOLAR PV

Although financially viable in the long run, solar PV still has high investment costs which stands as one of the main barriers in its adoption in the middle income countries. To be able to overcome this problem alternative financing schemes are being developed around the world. One of these innovative funding schemes is for single family buildings and it is based on solar power purchase agreements (PPA) or solar leasing. In the PPA system, which is being used in several countries such as the U.S. and Australia, a solar company or the utility company installs photovoltaic panels on the roof of the user and takes care of the maintenance. In return, the user agrees to buy the electricity produced by the panels, though at a lower price than the regular grid electricity. The solar company benefit through electricity sales, by using the roof space for free and by avoiding transmission line costs, while the user benefits from lower electricity costs. In the solar leasing system, the company installs and maintains the panels while users pay monthly fees to use the panels and eventually own them after the leasing period.

Yearly operating costs for the baseline scenario add up to PLN 206 million. Yearly operating costs of the alternative scenario are significantly lower, at PLN 177 million. This was achieved through operational gains from the use of photovoltaic panels for single family households,

[1] Detailed estimations available upon request.

as well as savings from using solar aided gas heating.

Figure 11 features a comparison of the total societal costs of the two paths. As can be seen from the graph, despite 40% increase of the amount of investment for the second scenario, it ends up being 15% cheaper when operating costs over 20 years are taken into account. Therefore, it is important to consider not only initial costs, but the savings over the lifetime of the technology.

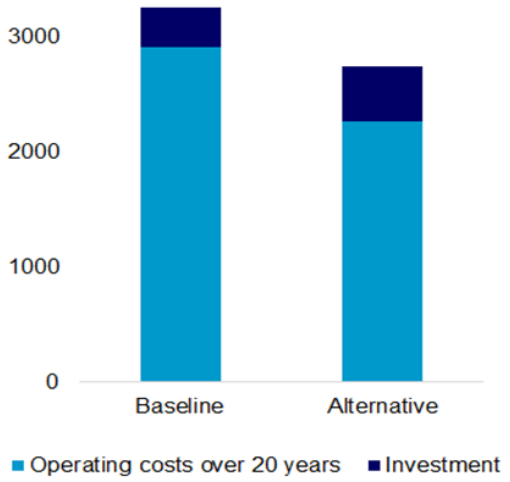


Figure 12 - Total cost comparison of the scenarios

COST-EFFECTIVENESS

Another important angle to look at the situation from is that of cost effectiveness. Cost-effectiveness illustrates to what degree the aim was achieved vis-a-vis the costs of intervention. In this case, it could be expressed by the amount of emissions reduced per zloty spent. For the two scenarios, the overall cost-effectiveness of both scenarios is the same at PLN 0,3 per gram of PM10 reduced.

However, a more precise way to estimate cost-effectiveness would be to look at the change in the background concentration per zloty invested. Then, if a 75% emission reduction from heating is not enough to cause a significant decrease in the background concentration, cost effectiveness of baseline scenario would equal zero.

Pollutant	Baseline	Alternative
Investment, PLN million	344	482
Total cost over 20 years, PLN billion	3.3	2.7
Emission reduction, % PM10	75	91
Cost-effectiveness, PLN/g	0.3	0.3

Table 3 - Cost and emission comparison of the scenarios

ADDITIONAL CONSIDERATIONS

Financial estimations presented above do not consider several important items for each of the scenarios. One such factor is the potential for job creation. The baseline scenario will not result in substantial growth in the number of local jobs due to its reliance on coal. Taking into account the existing trends in the market, the jobs, instead, will drain outside the city. The alternative scenario, however, creates a new industry of renewable technologies and the subsequent local employment, associated with installation and maintenance.

In addition, health effects should be considered. Under the baseline scenario, the problem of indoor pollution is more likely to prevail, with a higher number of households using coal for heating. Therefore, health costs will most likely be higher than in the alternative scenario.

Several private and public benefits stemming from the spread of renewable technologies should also be considered. Among them, increased property value for houses employing solar technologies, increased recreational value of the place and imagine of the city.

Furthermore, it suffers from a high degree of risks associated with locking into a declining industry with highly uncertain future. It builds a heating system that relies on a finite resource. It is then complemented by experimental solutions that are not proven on the market, such as blue coal and electrostatic precipitators, for which

viable business models have not yet been developed.

On the contrary, the alternative scenario relies on rising and progressive technologies that are proven through decades of successful deployment. They bring about huge operational savings and result in nearly emission-free sector, the only reasonable alternative for a town so heavily polluted. Perhaps even more importantly, it transforms Zabrze residential heating system to a renewable energy source, increasing self-sufficiency.

Finally, standards over fuel and boiler efficiency imposed by the European Union become more and more stringent, with no guarantee that a boiler that is considered efficient today will not have to be replaced in the future, or that a fuel that is allowed today will not be banned in several years. Over time, all these uncertainties can translate into price shocks, increasing the operating costs of the system, or a need for a significant additional investment. From a societal standpoint, the coal-based solution becomes too costly in the long term, once energy bills are added up, as well as in the short time, once additional costs such as health bills are accounted for.

ZABRZE AT THE CROSSROADS

The two scenarios were presented to illustrate the potential directions the city of Zabrze could take to deal with the low stack emissions from heating systems. Afterwards the comparison analysis was carried to identify advantages and disadvantages of the both propositions. It also proved that, in tackling air pollution issue, it is necessary to consider the broad picture, which is not solely based upon direct costs and benefits. Instead, indirect factors should also be taken into account.

Therefore, Zabrze is standing at a crossroads and it is thus important to set the right priorities for action. Continuing to depend on fossil fuels for heating goes against the prevailing trends in the market for renewables. The city has all the potential to become a transformative city, a place that is proud of its industrial past, but is forward-looking and visionary, that made a transition from hitting the charts of the most polluted cities in Poland and Europe to being a role model to follow. To realise this potential, a systematic approach to the issue of air pollution should be applied, one that recognises the importance of both sector-specific technical developments as well as soft measures.

COAL: A SPECIAL RESOURCE FOR POLAND

Coal has been a strategic resource for Poland which provided the necessary energy to shoulder the heavy industry between 1945-1989. It is the main energy resource that Poland had abundant and could rely on. Moreover, the industry has a unique position in the Polish history, through the role that labour unions played during the 1980s towards transition to independence and democracy.

All these aspects gave coal and coal industry a special place in the Polish national identity. However, coal is a finite resource, and considering the situation of coal industry and the energy demand projections of Poland, sooner or later another resource will have to come into the picture. In the best case, this new resource will represent what coal represents for Poland: independence and prosperity. Recognizing the place of coal for Polish identity is surely the first step for managing a necessary transition in the future.

ENABLERS

In the next part of the report, a toolbox of the soft measures will be described. The importance of such measures has to be underlined due to their high potential in solving the air pollution issue. First, they are necessary to foster technological transition described above. Furthermore, such measures aim to incorporate the complex social dimension, to avoid problems associated with fixating on technological solutions. One of examples of unintended consequences associated with downplaying the human factor is a case of blue coal in Silesia. Last year, blue coal was distributed among residents in several Silesian towns, including Zabrze. The first days following the intervention, people were using the new fuel. The solution seemed to have worked. However, after a short while, people started to sell the new, more expensive, coal elsewhere and buy cheaper conventional coal to heat their houses instead, earning money in the process.

The toolbox includes measures such as enhanced collaboration, awareness building, strategic recommendations, data management and nature-based solutions.

THE ROLE OF USER

During the visit to Zabrze, an interesting phenomenon was observed. Local heating systems rely on comparatively higher temperatures than those in Sweden - around 26°C compared to Swedish 22°C. In case it gets too hot, the problem is solved by opening the windows with the heating system on instead of adjusting the heating equipment. This results in huge losses from energy efficiency perspective. Higher indoor temperatures increase the energy demand for the household. Why not enjoy a pair of cozy woolen socks and a cup of tea in a mildly warm room instead?

STRATEGIC APPROACH

Since air pollution is so vocal among other issues in Zabrze, we recommend it to be better incorporated into the City Development Strategy. In the current version of the strategy, air pollution is only mentioned a handful of times under a broader range of environment-related targets. City Development Strategy is intended to be working across the departments and, thus, has potential for bringing about cross-departmental collaboration, much needed in the field of air pollution. Including air quality goals in it will help to fix the fragmentation of current efforts to tackle the issue in Zabrze.

LOCAL AIR POLLUTION GOALS IN ESSEN, GERMANY

Many of the more polluted cities of the world start developing separate air pollution plans or strategies that encompass different areas and function across departments. Such plans usually aim at informing other development plans that have relevance for the topic, as well as providing framework for urban decision making. An integral component of these is air pollution goals.

Essen, a twin city of Zabrze, is located in Western Germany and has a population of around 600 000. It is facing many problems that Zabrze is facing, having been an important industrial center in the 20th century, with blossoming coal and steel industries. The city's Air Quality Strategy focuses on PM10 and NO_2, and has two stages: 2020, by which the levels should be kept below the EU Directive threshold, and 2035, by which WHO guidelines should be consistently met [16]. It, thus, introduces quantitative objectives for both air pollutants. The strategy has several focus areas, including energy efficiency, mobility, consumer conduct, and business and industry; and was preceded by an extensive work on establishing a monitoring and measurement network and conducting emission inventory in order to track progress towards the goals.

Potential quantitative goals and indicators:

Concentrations in certain pollutants are tracked under the current strategy within the array of environmental indicators. Downward dynamics that were observed for PM10 and SO_x for the

period of 2010-2016 are the results of the changing meteorological conditions, rather than improvements through targeted efforts. Therefore, it is important to choose more appropriate indicators to track the progress, such as weather-adjusted air pollution concentrations. In addition, air quality goals could be considered for the next issue of the Strategy.

Potential qualitative goals:

- Air pollution effects should be assessed for every urban development decision undertaken;
- No development decision should have a net negative effect on air quality.

In addition, goals related to the housing sector and any new developments in the housing sector should be considered.

DATA MANAGEMENT

Monitoring, inventory and modelling are all necessary steps in order to develop a comprehensive urban air quality strategy. One important role of monitoring is to provide input data for inventory, which, in turn, serves as a basis for modelling. Modelling, then, allows for estimation of effects of different strategic alternatives. After the strategy has been implemented, monitoring combined with modelling helps to track the progress towards the achievement of the goal.

Monitoring

We have looked into qualitative and quantitative aspects of air pollution measurement in the city. According to our findings, the monitoring system established in Zabrze is in line with all major requirements. However, Zabrze could benefit from obtaining accurate data on peak emissions. Traffic emissions can be tracked, as well as pollutants emitted in the close proximity to coal heated residential buildings. Recognizing costs associated with additional units of measurement equipment, cost effective measuring and sampling techniques are suggested.

BIG DATA FOR AIR POLLUTION MEASUREMENT

Many practitioners see small decentralized measurement devices as the future of urban air quality measurement. The devices, such as the one on the picture, developed by the Institute for Chemical Processing of Coal, can be attached to both mobile elements such as city bikes, or stationary units, such as municipal buildings. Data obtained by such devices can then be gathered alongside geolocation, creating a virtual map of pollution concentration around the city. Such network of low cost devices can give the authorities a more precise picture of pollution in the city, reducing the need for modelling and solving many of the problems of traditional measurement stations. In addition, if distributed among citizens, it can contribute to awareness creation. From citizens' perspective, such devices can help lower their exposure by avoiding heavily loaded streets or staying at home when the concentration levels are high.

Screening methods such as a mobile laboratory, diffusive sampling and manual techniques are not only cost effective, but easier to assemble in comparison with the fixed monitoring stations.

Inventory

Establishing an emission inventory is the next step. Emission inventory is a quantified data set of all air emissions by source, timespan and pollutant, representing the main data input in municipal air quality management. It helps the municipalities manage the issue in a more targeted, and thus cost-effective, way, by giving a clear picture of where emissions come from and what is the potential for reduction.

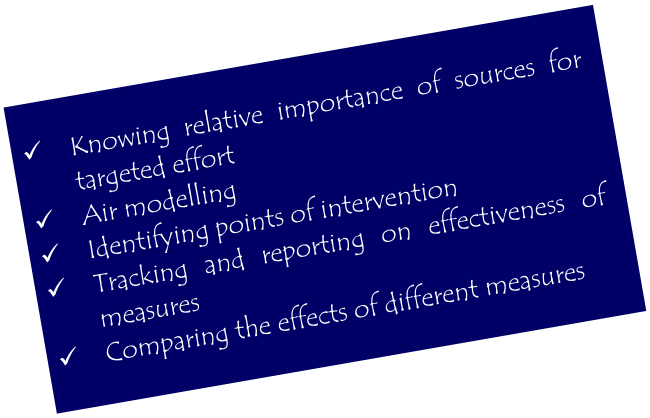


Figure 13 - Benefits for conducting emission inventory on a city level

Following the model implemented in Malmö, Sweden, an emission inventory can be realized as a PhD project, with the city ordering the research. To optimize the resource intensity of the process, the inventory should be developed at a right level of detail in relation to the relative contribution of sources.

Modelling

For a smaller city like Zabrze, well-tailored air pollution modelling system could become a cheaper alternative to expanding the monitoring network. In addition, introducing the spatial dimension through modelling could help getting a more detailed picture of population exposure in different parts of the city. Furthermore, modelling could serve as the basis for forecasting. To reduce the costs of modelling, the urban area Zabrze is part of could jointly purchase rights for using the model and split the bill.

NATURE-BASED SOLUTIONS

One of the options that could be considered are nature-based ones. Broadly speaking, these solutions exploit nature's ability to tackle environmental issues the cities face. They usually consist of careful planning and management of the city's green areas. In tackling air pollution, nature based solutions should be regarded as complementary measures, rather than the main points of intervention due to their limited potential and rather localized effects. However, such solutions bring about several co-benefits that make them attractive for cities to implement, including aesthetic value.

Effects of the "green infrastructure" on air quality has long been researched. Among numerous benefits are the following:

- absorption of pollutants and turning it into their biomass
- removal of gaseous emissions
- decreasing the concentration of VOCs levels
- mitigation of the heat island effects and decrease of the temperature
- modification of the air movements in the streets

It must be pointed out that not all trees are equally good for this task. The absorbing capacity differs greatly between species. During the visit in Zabrze, experts pointed out that, even though the total area covered by trees in Zabrze is relatively high, trees contribute little to tackling the issue due to poor choice of species. Moreover, physical parameters of trees matter as well, such as height, crown volume and density, as well as the position on them within the city.

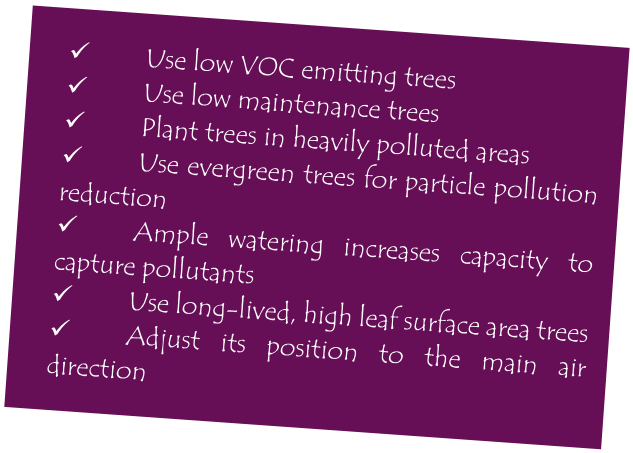


Figure 14 - Recommendations for trees planting

Related solutions are green roofs and moss walls. The benefits from moss walls are twofold: they create a physical barrier for pollution spread and absorb the pollutants. This makes them suitable for installing alongside the heavily polluted roads. Green roofs, on the other hand, contribute to reduction of O_3, NO_2, PM, SO_2. However, the cost of green roofs per kg of pollutants removed is higher than for trees.

AWARENESS

One of the crucial enablers for the change of the whole system is raised awareness. There are several major benefits associated with the increasing awareness on the issue that can be expected. First of all, it can boost the pace of adoption of cleaner heating technologies and the consequent reduction of the emissions. Furthermore, it can contribute to managing the exposure of population, significantly decreasing negative health effects and associated costs. Besides, it can considerably improve the image and appeal of the whole city. The streets of Zabrze can become more inviting for locals, visitors and new businesses.

With increased public awareness comes increased responsibility for city administration. But it can also be seen as an opportunity, as with increased awareness the residents of Zabrze can also support and appreciate the efforts of the city on the issue.

Several areas of knowledge should be communicated through the awareness campaign (Figure 14).

Figure 15 - Information to be communicated

First is the broad issue of air pollution, particularly, the causes, sources and effects of it. People should feel the urgency of the problem and the importance of tackling it. Secondly, citizens need to be aware that the heating systems based on coal are the most significant contributors to the air pollution in Zabrze. Toxicity of solid fuel burning, let alone burning garbage, should be made clear. However, even these would not be enough without suggesting reasonable heating system alternatives, and communicating the funding opportunities offered by the city (PONE/KAWKA). Particularly, the application procedure, waiting times, needed documentation should be communicated. This would help citizens to make informed decisions for heating system changes.

Poland in general is doing a good job in communicating information on air pollution via a user-friendly website. Publicly available online information includes many aspects, for instance, maps, forecasting, health information, annual and daily measurements. However, when it comes specifically to Zabrze, no extra efforts in communicating information about air pollution were identified, except those mandated by law. This cannot be regarded as sufficient given the critical situation in the region. Citizens can greatly benefit from locally specified data. It is particularly so for vulnerable groups of citizens (children, elder people, pregnant women) and those belonging to the risk groups (e.g.

respiratory problems, ozone-sensitive). For these groups, personalized recommendations can be issued. In this respect, higher awareness can help to alter the habits of people, avoid the health adverse effects and eventually even to some extent decrease the air pollution.

What to communicate:

- Maps: zonation of Zabrze city with the display of up-to-date information in each zone
- Healthcare information: personal actions to protect oneself
- Warning and alerts during the peak of air pollution

Through what to communicate?

- Social media and apps appear to be the most cost-effective communication channels (reference air implementation pilot)
- Send text messages with the updates to the citizens, who requested them
- Broadcast the information on the city street panels and the motorways

How to communicate?

- User-friendly and visually appealing
- Not too technical
- Targeted depending on a group of residents

COLLABORATION

To combat the issue of air pollution, the efforts of just one party are not enough. The problem is too complex and fragmented to impose responsibility on a single city department. Rather, involvement and collaboration of multiple stakeholders is necessary. In return, collaboration can boost synergies between the departments, facilitate knowledge exchange, help to arrive to a shared vision and increase awareness.

For instance, the City Planning Department was not sufficiently involved during the development of the EU-funded project on expansion of city's green zones. However, the project could greatly benefit from the department's input. Another obvious example is the absence of collaboration between the institutes for air pollution measurements and the Ecology Department, which ultimately operates with this kind of data. Finally, the Ecology and City Planning Departments were downplaying the role of nature based solutions, thoroughly analysed in the same Institute of Environmental Engineering. These and many other examples emphasize the importance of the dialogue between different stakeholders.

Stakeholder analysis

Figure 16 - Main stakeholders in air pollution issue in Zabrze

The most influential group of stakeholders is found in the second quadrant. These actors not only care a lot about the issue, but can initiate, support and make a change, and should be prioritized when dealing with the issue. Furthermore, in theory, actors in the fourth quadrant should be informed about carried out activities. However, if they are empowered more, they can boost the transformation significantly. For instance, solar companies, urban planning department can have significantly more weight in limiting city developments unfavorable for the air quality city.

After all the concerned stakeholders have been identified, potential synergetic connections can be pointed out (Figure 16).

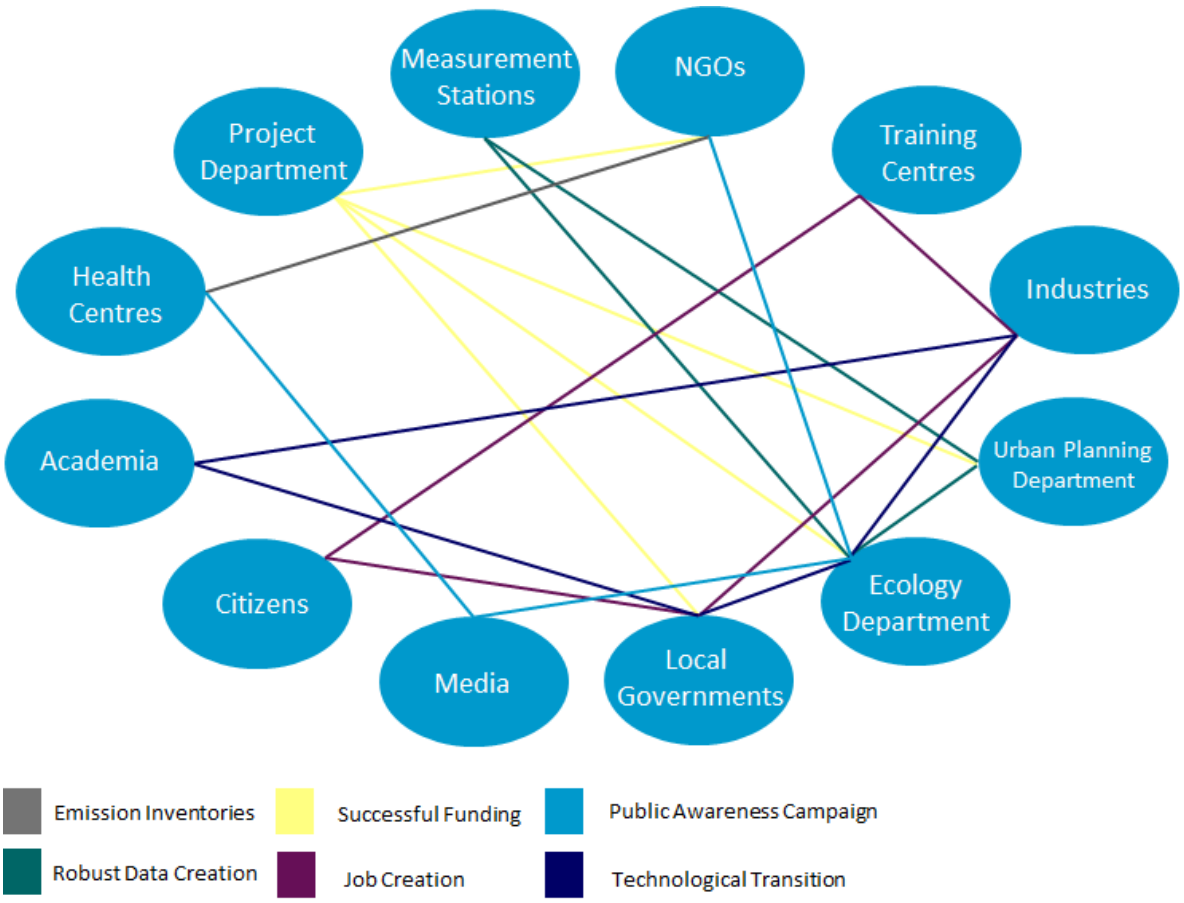


Figure 17 - Collaboration projects

Robust Data Creation & Emission Inventories

For the reasons stated in previous chapters, robust data should be continuously accumulated, such as emission inventory. Conducting emission inventory is time consuming and labour intensive, which is why several parties' involvement is highly recommended. Joint participation of Air Quality Measurement Station, the Ecology Department and PhD students from the Institute of the Environmental Engineering will allow for achieving the best possible results.

Successful Funding

In applying for the European and regional funding, the Project Realization Department can significantly benefit from the input of parties that have a deep expertise in the project area. For instance, fundraising department could seek insights from the Urban Planning department and the Institute of Environmental Engineering in applying for the project on expanding Zabrze green areas.

In addition, special loan conditions could be developed in collaboration with financial institutions to reduce the burden of upfront costs for renewable heating alternatives.

Job Creation

Zabrze used to have around a dozen of coal mines, however, only one is still operating. This forced a lot of people to seek job opportunities in other cities or regions, with some left with no job at all. With the help of educational centres, vastly present in Zabrze, it is possible to keep this labour force in the city, through re-qualifying and involving them in the provision of different services, such as solar equipment installation.

Public Awareness Campaign

To increase awareness, multiple stakeholders should be involved. For example, doctors could inform the citizens about the health effects, local media could be helpful in reaching out to wider audiences, PR agencies could help creating effective campaigns. Ecology department can collaborate with activists from Zabrze itself and a bigger NGO Katowicki Alarm Smogowy from Katowice, as well as Krakowski Alarm Smogowy, all having vast experience in effective mass communication strategies.

Technological Transition

All potential technologies should be carefully considered, and a thorough cost-benefit analysis should be performed to guide technology transition. Therefore, equal participation of both renewable energy companies and fossil fuel companies in the dialogue is crucial. In addition, academia could contribute with an impartial analysis of advantages and disadvantages of the alternatives.

CONCLUSION

Upon the request of Zabrze Municipality, this report looked at the air pollution issue in the city of Zabrze. Analyzing the publicly available air pollution data, the main contributing local source to air pollution was identified and an alternative heating system was suggested and compared to the coal based heating system. Moreover, several other measures that the city could do to tackle the issue of air pollution were suggested. The main conclusions from our report are presented below.

First of all, the main source of air pollution in Zabrze is the coal-based residential heating sector, thus, this sector should be at the center of the efforts. Efforts on increasing the energy efficiency of the buildings, replacement of inefficient furnaces, legal requirements on the quality of fuels and expansion of district heating system are all positive steps and these efforts should continue with increased strength.

On the other hand, city of Zabrze is standing at the crossroads. Our calculations show that continuing the reliance on coal for heating might result in high financial costs and societal losses in the long term. Thus, a different path, a gradual change of the heating systems in the city to cleaner and renewable alternatives stands out as a necessity. Considering the fact that any decision on heating systems is a long-term decision and comes with considerable costs, it is recommended that the decision is based on thoroughly conducted cost-benefit analysis of alternative systems where not only the equipment and running costs but also the all the environmental, social and health costs are taken into account.

Any approach to environmental problems requires long term perspective, thus it is extremely vital to incorporate air pollution into the City Development Strategy and other long term strategic documents. This would enable the city to take control of the air pollution in the future by considering the effect of urban development projects on air quality.

Air quality data management is crucial for the development of the correct strategical approach. Monitoring the air quality is the first step to a comprehensive data management. Screening methods and portable devices for air pollution monitoring could be used to give a clearer picture of the state of air quality in different parts of the city and the exposure levels for population. Based on the data gathered through monitoring, an emission inventory specific to Zabrze should be established.

An underpinning effort in improving the situation is the increased citizen awareness. Higher awareness among the citizens on the causes/sources and negative effects of air pollution will result in stronger public support for the measures to be taken by the authorities and more appreciation for the efforts to tackle the problem. Moreover, increased awareness about cleaner heating system alternatives and available financial support will boost the pace of adoption of new technologies.

And lastly, the problem of air pollution is too complex to be handled by a single department, thus multi stakeholder collaboration is central to successfully dealing with air pollution. This is an area Zabrze has room for improvement. The possible areas for collaboration range from data collection to public awareness, from technological transition to financing, where city administration, scientists, civil society and businesses can share knowledge and create synergies that is necessary to transform Zabrze into a sustainable city with clean air.

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APPENDICES

Advantages	Disadvantages
BASELINE SCENARIO	
Electrostatic precipitator	
Reduction of on the main polluter (PM) Easy to install, no need to change the furnace No behavioral change needed =>fast pace of adoption	Zero reduction of other critical pollutants (PaP, SOx,NOx) Significant price given the reduction potential Regular need to empty the dirty grade with ash Limited incentives for households to install
Cleaner coal/Blue Coal	
Lower emissions compared to conventional coal No behavioral change needed =>Fast pace of adoption Better combustion quality => less amount of solid fuel needed No further subsidies needed	Non-renewable High energy demand for production Higher price than cconventional coal Dependence on an industry in decline Indoor pollution still an issue
Natural Gas	
Much lower emissions at source in comparison to solid fuels Comparatively small amount of waste gas and heat Less emissions at the source of energy generation	Non-renewable Dependence on imported energy source Need for further infrastructure = > high installation costs Low levels of carbon monoxide as small source of indoor pollution Requires operational checkups
ALTERNATIVE SCENARIO	
Solar PV	
Renewable and local source No emissions Favourable net-metering framework of Poland Producing energy even in low temperatures Increasing appeal of the city	High upfront investment cost Relatively low efficiency of the currently available PVs Limited surface area for multi-storey buildings
Air to water heat pump	
Zero emission at the user end Very high efficiency No indoor pollution factor Self-sufficient and independent supply Lower running cost in the long-run	High up-front costs High cost of electricity depending on the price Might need a back-up electric heater in case of very low temperatures
Solar Water Heating	
No emissions Low cost Can assist other heating sources and increase efficiency Easy to install and modify existing infrastructure Boosting affordability of the heating equipment Gradual change in greening the energy mix	Use of the fossil fuels as a primary energy source Need for a main heating system to assist

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