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Review

Inclusion of Renewable Energy Sources in Municipal Environmental Policy—The Case Study of Kraków, Poland

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Abstract: This article reviews the evolution of local environmental policy in the context of energy transition and particularly the implementation of RES. The study concerns Kraków, whose policy has been compared with other cities and metropolises and was analysed in a timespan of about 30 years. It was hypothesised that, until recently, RES were treated in the city with reserve concerning their feasibility in local environmental and economic conditions, but since RES have been appreciated as a viable means to effectively combat low-stack emissions, the local air quality targets have been integrated with global decarbonisation goals. This launched a dedicated subsidy stream for RES installations and contributed to the sharp increase in the number of installations. Trend analysis techniques have been used to study environmental indicators in relation to the evolution of municipal policies, the expenditures, and their effects. The review confirms that the implementation of RES had not been a priority for Kraków but a complementary measure to those aimed at improving air quality. The recent integration of the environmental and RES policies has been the next step that is now helping to pursue both the city's strategic goals: further air quality improvement and climate neutrality by 2050. Kraków may serve as an example of a city that has treated RES in a manner adequate to local conditions and capabilities, thus achieving the intended goals.

Keywords: air pollution; earth and environmental science; environmental policy; integrated planning; low-stack emission; renewable energy sources; transition; urbanism

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1. Introduction

1.1. Rationale

The increased use of renewable energy sources (RES) has become a global trend, and the world is becoming united in its efforts towards energy transition to combat climate change and achieve sustainable development. The relevant measures are taken at the international and national levels as well as locally, where RES are implemented to improve the communities' sustainability and quality of life.

The use of RES may serve various purposes from power generation development through ensuring energy security to care for the environment. For RES to become an effective means to achieve such goals, a deliberate and purposeful strategy must be adopted and pursued that considers locally specific factors and barriers to renewable energy development. The measures are usually outlined in a RES implementation policy for a given geographical, economic, and social context.

This paper discusses the city of Kraków where, owing to severe air pollution caused mainly by low-stack emissions, one of the key challenges is to improve the environment. Taking up the topic of the possible impact of the implementation of RES on the quality of the local environment, we were looking for a comprehensive study that would show the city's renewable energy policy from a historical perspective. It turned out that there is no academic study that would comprehensively show how the local or regional government of Krakow included RES in their environmental policies. Moreover, we have not found any scientific review that analyses Krakow's policy from a historical perspective that would show how the activities of local or regional government translated into the state of the environment.

We decided to fill this knowledge gap. To narrow the scope of our research, we focused on the relationship between city policy and air quality, which has been the main environmental problem of the city for decades. Due to the lack of studies to which we could refer, the time scope of our research had to be drawn broadly. The main time frame of our review starts with the fall of communism in 1989, when the city and the region obtained a real impact on environmental policy and reliable data on the state of the environment has become available.

1.2. RES Inclusion in Policies at Different Levels of Urban Management: Literature Review

Strategies aimed at developing RES differ at all levels—international, national, local, and between cities and rural areas. A city is a complex system and can be analysed as a matrix of interconnections between the economic, societal, and environmental systems that together require integrated management. This can be supported by the implementation of relevant policies, within whose framework RES are increasingly used as an important measure to achieve sustainable development, particularly energy self-sufficiency and environmental goals. According to Lutz et al. [1], an agent of crucial importance for transitioning to a RES-based energy system on a regional scale is understanding the factors which enable the transition: knowledge-sharing mechanisms, good practices in the deployment and use of renewable energy, and the establishment of common goals for the community of stakeholders. Such an approach might require cooperation at the international level, as in the case of ASEAN-EU [2] or the countries of the Gulf Cooperation Council [3].

In countries that are members of multinational communities such as the EU, the degree of integration may influence RES development through obligations on member states and financial support instruments. It is however important to understand the relationships between EU renewable energy policies and local conditions. Kotzebue et al. [4] present an example of the incompatibility of national Malta policy and the EU policy framework. Dusmanescu et al. [5] present the difficult implementation of the EU RES policy in Romania, in the context of its particular socio-economic conditions. The example of Lithuania [6] showcases however a considerable increase in the share of RES in the national fuel and energy mix and a reduction in GHG emissions and air pollution. Thus, it is not just membership in formal structures that contribute to the development of RES. For India, it was the signing of the Paris Agreement that provided the incentive for the introduction of a number of policies to support RES [7].

The integration of policies on the national and local levels is another key to the successful implementation of RES [8]. The implementation gap between national policy and local practice sometimes fails to meet energy goals [9]. As top-down instruments and guidelines are important at the initial stage of RES policies preparation, it is knowledge of success factors in RES implementation that is crucial in the next stage, and then the know-how that comes from own experience [10]. The achievement of energy transition goals might be reliant on the proper use of the interim evaluation of the chosen path.

Cities and their metropolitan regions are always complex areas with their specificity, where the implementation of new energy systems requires the adoption of appropriate, tailor-made evaluation criteria [11]. With careful planning, renewable energy should bring far-reaching economic, environmental, and social benefits also to people who live in remote rural, underdeveloped and sparsely populated areas with unmet energy needs [12–15]. Pilot RES projects, as in Bangladesh [16], present solutions for streamlining policy implementation and establishing favourable conditions in the country.

It is the policies that determine the rate of RES development, but it is the rate of development that influences policy making. In China, despite the rapid development of renewable energy installations, challenges are emerging which require improvements in the legal framework, e.g., a reasonable renewable energy tariff policy [17].

Another aspect is the technological level of own industry and R&D capabilities. Those who do not want to become importers of new energy technologies must keep up with the changes [18]. Usually, the development of RES in cities is an evolutionary process, but there are also revolutionary, cutting-edge projects such as Masdar City in Abu Dhabi [19]. This particular example shows that being a zero-carbon city requires compact urban design, green architecture, walkability and sustainable mobility solutions coupled with integrated planning in spatial and economic terms.

More cases are confirming that the goal of energy transition requires an appropriate urban planning approach, whether in small towns [20,21], or metropolises such as Frankfurt or Munich in Germany [22] or a group of 53 cities and towns in the United States of America, Canada and Mexico which aim to meet 100% of energy needs by using wind, water (including geothermal reservoirs) and sunlight [23]. Such examples place pressure on cities worldwide to be smart and implement RES in a model way [24]. Some of them, such as Cuenca in Ecuador, have high ambitions of moving to 100% renewable energy by 2050. This will require reforms at the legal, business, and technological levels [25].

To achieve the transition to renewable energy in a democratic system, conflict-free policy coordination ensured by a participatory process is required [26]. Support should be provided through appropriate research and analysis tools that facilitate RES systems planning [27], energy supply and demand modelling [28], and the development of energy management strategies and policies balancing environmental, economic, and social dimensions [29,30]. The methods need to be appropriate to the set of objectives, such as achieving energy self-sufficiency [31] but also well-being and quality of life which always need to be regarded as priority goals in urban management.

Municipalities are often subject to financial pressure and any investment projects must be properly justified. Therefore, supporting methods such as project cost-effectiveness comparisons for multiple urban locations and technological options with the use of data obtained from wind and solar resource forecasting ought to be used in the process of responsible RES implementation [32]. An analysis of the profitability of investments in the Krakow region of Małopolska in selected systems based on RES has been performed at the Cracow University of Technology (CUT) [33]. Three variants of systems based on combinations of heat pumps, biomass boilers, solar collectors, PV panels, and wind turbines for heating and hot water production have been analysed on a residential building typical for the region and compared with a traditional heating system. It was confirmed that the profitability of a given investment depends on both technical solutions and subsidies, and the latter can be a key element of a regional RES implementation policy.

The necessity, directed by the EU [34], of radical improvement of the energy performance of buildings, requires covering their energy needs to a significant extent from renewable energy produced on-site or nearby. Poland has adopted relatively ambitious nearly zero-energy buildings (NZEB) parameters [35]. However, one of the main reasons behind RES implementation strategies may be air quality improvement, such as in Kraków, where RES have been identified as an effective solution to fight particulate matter (PM) and benzo(a)pyrene (BaP) emissions [36,37]. In this case, local air quality targets should be integrated with global decarbonisation goals [38] to make the RES development and environmental policies consistent [39].

1.3. Air Quality Problem in Kraków

Kraków is the second-largest city in Poland in terms of population and surface area. It has a population of over 780,000 residents [40] but can be considered as a million city, for a university student population of over 150,000, and a significant number of tourists throughout the year (in 2018, it hosted approximately 13.5 million visitors, of whom

3.1 million came from abroad [41]). Kraków is also surrounded tightly by smaller towns and its Larger Urban Zone has 1.38 million inhabitants. The city is the capital of the Małopolska (Lesser Poland) region (Figure 1) and a vibrant economic centre with the largest cluster of business service sector companies in Poland in terms of the number of people employed. In the Tholons Services Globalization City Index 2019, Krakow was placed among the Top 100 Super Cities taking 11th position (6th in 2018) [42]. In the fDi's European Cities and Regions of the Future 2020/21 ranking, Kraków took eighth place in the Top 10 Large European Cities of the Future 2020/2021 [43]. The city owes its high-ranking positions primarily to its human and cultural resources. According to CEE Investment Report 2019: Thriving Metropolitan Cities, Kraków was third in EU-28 (behind London and Warsaw) in the category "Share of population with higher education" [44].

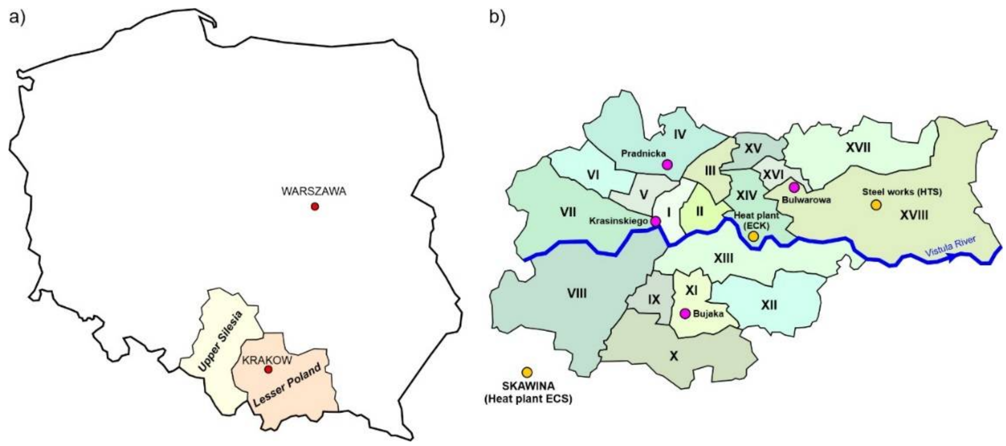

Figure 1. (**a**) The map of Poland with the location of Krakow, Warsaw and two regions: Lesser Poland and Upper Silesia. (**b**) Krakow boroughs and the location of the places mentioned in the text: HTS—Sendzimir Steelworks, ECK—Heat and Power Plant Krakow, ECS—Heat and Power Plant Skawina, and measuring stations: Pradnicka St., Bujaka St., Krasinskiego Av., Bulwarowa St.

Despite that potential and its tourist and economic attractiveness, for many years Kraków also used to be close to the top in the ranking of cities with the most polluted air in UE. It was only in 2020 that it moved down that infamous ranking [45,46].

The immediate reason for this change is probably the blanket prohibition on the burning of solid fuels within the city limits, which has been effective since September 2019. The ban on burning coal and biomass has forced the replacement of outdated boilers and stoves, which were the main cause of low-stack emissions and poor air quality for decades.

However, it is often forgotten that the problem of poor air quality has plagued Kraków for at least seven decades and has been conditioned by the economic history of the city and the entire country. After the communist dictatorship was installed in 1944–1948, many energy-intensive industries were developed, often based on outdated technologies unwillingly imported from the Soviet Union (USSR). Such projects resulted in severe environmental degradation. Southern Poland, and in particular the Upper Silesia and Lesser Poland regions (Figure 1), became the centres of heavy and chemical industries where hard coal mining and metallurgy were favoured. In 1954, the Sendzimir Steelworks (Lenin Steelworks at that time) (HTS) was launched at the eastern border of Kraków. It was one of the biggest metallurgical plants in Europe, intended to redefine the economic and social character of the city that up to that point was perceived by the communist regime as the hostile centre of the reactionary bourgeoisie. The consequences of that decision included environmental effects such as catastrophic air quality.

By the 1980s, with steelworks producing annually 6.7 million tons of steel and emitting 9% of the gaseous pollutants in the whole of Poland, Kraków was on the edge of the environmental disaster [47]. The pollution was equally damaging to people and historic monuments, because of acid rains. The turning points came in 1978 when the entire Kraków

Old Town was chosen as one of the 12 sites in the world inscribed on the first UNESCO's World Heritage List, and in 1980, when the Polish Ecological Club (PEC) was founded in Kraków during the early days of the Solidarity movement. PEC was the first legally established independent environmental NGO in the Eastern Bloc, and the first organisation to openly protest the imposed energy-intensive economy based on heavy industry. The first significant achievement of the young environmental movement was closing down, in 1981, the extremely harmful aluminium smelter in Skawina, at the southern border of Kraków. Solidarity, which was a social movement with 10 mln members, also brought a breakthrough in planning policies and conservation practices.

In 1989, after communism finally fell in Poland, and local democracy was reinstalled by the national Act on Municipal Self-Government (1990), the city regained the freedom to shape its future, including economic and environmental policy. Air quality has remained high on the agenda for many years. The elimination of pollution has been an environmental objective, but it has had an equally important social dimension, clean air, which improves the citizens' health and the quality of life in the city, and it is important for the economic competition since wellbeing is of growing importance in the global services market.

The economic transition appeared for Kraków an easier challenge than changing the distributed heating installations in the city itself and the region. Only the last few years have brought a critical mass of social, political, technological, and economic factors, which made it possible to break the deadlock in the game for both clean air and energy transition.

In the next sections, we propose a unique insight into the three last decades of the City's transformation. In Section 2, we present the aims, materials, and methods we have used to confront the evolving policies with their effects. In Section 3, we exhibit the synthesis of the results of our search concerning implemented provisions and their outcomes. In Section 4, we discuss our findings on the background of the means to tackle low-stack and GHG emissions.

In the conclusions (Section 5), we emphasize the contribution of this research to scientific knowledge and suggest possible directions for further studies. We also summarise the most important implications, confirm our hypothesis and propose a policy recommendation.

2. Aims, Materials and Methods

The objective of this article is to review the evolution of Kraków's environmental policy in terms of air quality improvement in the context of energy transition and implementation of RES—which was never performed before. The research hypothesis is that for several decades RES were treated with reserve concerning their feasibility in local environmental and economic conditions, thus not actively supported by the local government. Only recently, RES have been appreciated as a viable means to effectively combat low-stack emissions and also pursue the new goal of the city that is climate neutrality. The recent inclusion of RES in municipal energy and environmental policies led to the integration of the air quality and climate policies and has been increasingly helping to pursue both the strategic goals of the local government: reduction of air pollutants and climate mitigation.

To test this hypothesis, historical environmental data has been analysed alongside the measures in local policies and actions taken to address the environmental problems. We examined annually published State of the City Reports 1991–2019 [48] which gather information from municipal departments, city units, companies and organisations representing all three sectors. The reports contain data concerning various areas of the city's functioning, thus comprehensively documenting its development and the activities of the local stakeholders, the municipality, and the regional government.

Based on this, particularly the data revealing the annual average concentrations of air pollutants: PM_{10}, $PM_{2,5}$, SO_2, and NO_2, we used trend analysis techniques to study the changes of environmental indicators in relation to the evolution of municipal environmental policies. For the years 2012–2019 when the municipality has implemented a more active policy involving its own financial resources, we also examined the expenditures and effects of the implementation of the Low-stack Emission Limitation Programme such as the data concerning liquidated coal furnaces and boilers, and assembly of RES installations.

Thus, we analysed whether and how RES were integrated into Kraków's environmental policy and what effects that policy produced in the analysed three decades. The RES-related programmes and implemented tools have been reviewed in historical Kraków's strategic and operational documents, to determine the role of particular RES in the city's transition. We also reviewed recent strategic documents of the city, i.e., Low-Carbon Economy Plan [49], Kraków's Development Strategy 2030 [50] and RES Development Programme [51] in terms of their quality and consistency regarding transformation towards sustainable energy and reduction of GHG emissions.

3. Results

3.1. Historical Changes in Kraków Air Quality

At the beginning of the 1990s, the main sources of air pollution were gaseous and PM emissions from Kraków's industrial and municipal facilities, including the local CHP plant and one of the largest industrial plants in Poland—the Sendzimir Steelworks (HTS, Figure 1). Moreover, some pollutants originated outside Kraków: from the Upper Silesian Industrial Region, whose borders reach 30 km to the west of Kraków (Figure 1), and Skawina ECS Heat and Power Plant situated 15 km to the southwest (ECS, Figure 1). Western winds prevail in the region, which favours the transfer of pollutants from that side.

During the heating season, low-stack emissions originated from thousands of domestic boilers and stoves fired by solid fuels and not equipped with flue gas filters. Steady increases in NO_2 concentrations also were recorded in the 1990s, exceeding permissible levels. The cause was the growing number of motor vehicles, often in poor technical condition. Due to the characteristic topography of Krakow, in some years, smog-type conditions persisted not only in autumn and winter but also in summer when a continental high-pressure system prevailed over the city, bringing high air temperatures, low-lying inversion layers and near-zero wind speeds.

During the whole decade of the 1990s, smog alerts were still caused by SO_2 and PM. Although their concentrations were falling (Figure 2), Kraków was ranked near the top in terms of total emissions of particulates and gases, as well as SO_2 emissions, among cities with more than 100,000 inhabitants. Large industrial plants remained the main source of emissions despite systematic efforts at their reduction. Limits for average annual SO_2 and PM concentrations were exceeded as a result of combined low-stack emissions, traffic-related pollution, power generation by local utilities and the inflow of pollutants from neighbouring areas.

After 2000, the impact of industrial plants on air quality systematically decreased, mainly due to the legislation that laid down emission limits. At that time, the burning of solid fuels in household boilers and stoves became the prevailing cause of PM emissions. Even their gradual modernization was not bringing positive effects due to the growing popularity of domestic fireplaces. Another reason for the increase in PM10 concentrations was the ever-increasing traffic. The situation was additionally aggravated by periods of adverse climatic conditions—the inflow of polluted air masses, high humidity and poor ventilation.

In 2002, the methodology of air quality measurements changed—manually operated measurement stations were replaced by more accurate automatic ones. This resulted in much higher results than those previously recorded (compare Figures 2 and 3). In subsequent years, air quality in Kraków was still described as "unsatisfactory" due to the failure to meet the standards for PM_{10} and $PM_{2.5}$ as well as NO_2 concentrations (Figure 3). Even in 2018, the annual average PM_{10} and $PM_{2.5}$ concentrations were still above limit values at all measurement stations, and the number of days per year when those standards were exceeded was many times higher than the number of days below the permissible level. The annual average concentration of NO_2 recorded at the measurement station in one of Kraków's main thoroughfares (Krasinskiego Av.) was significantly higher than the relevant permissible level.

It was not until 2019 that air quality in Kraków significantly improved, although state environmental monitoring results still demonstrated that some permissible concentration levels were not being met. The improvement in air quality was maintained in 2020 and then for the first time in decades the city dropped in the ranking of the most polluted cities in Poland [46].

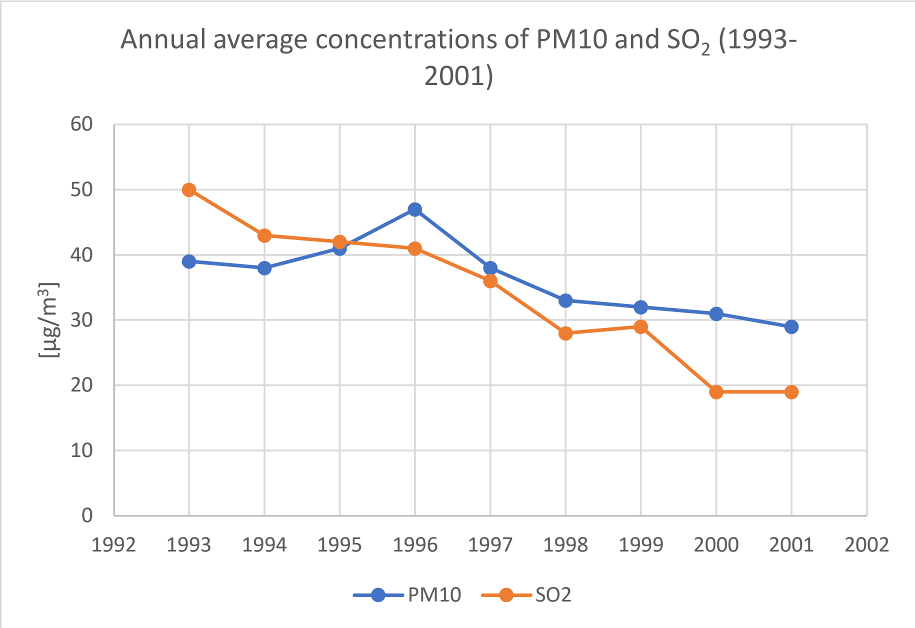

Figure 2. Annual average concentrations of PM_{10} and SO_2 in Krakow in 1993–2001 (based on the State of the City Reports 1993–2001 [48]).

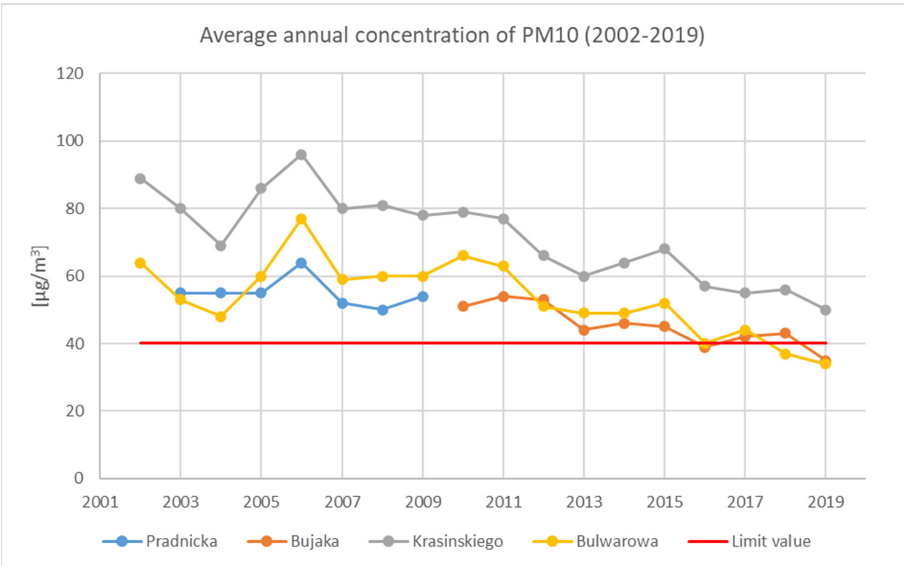

Figure 3. *Cont.*

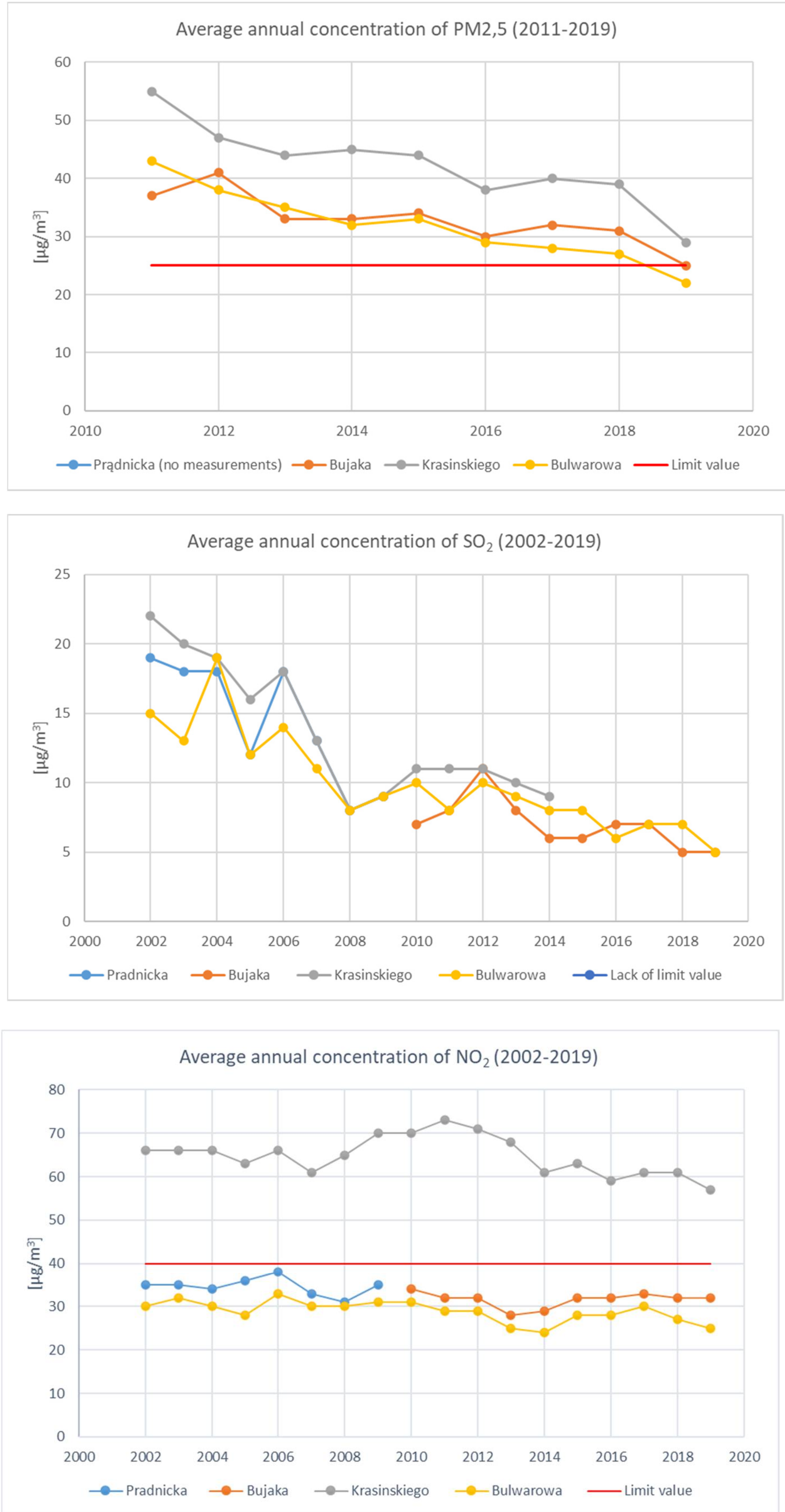

Figure 3. Average annual concentration of air pollutants in Kraków in 2011–2019 (based on the State of the City Reports 2001–2019).

3.2. Measures Taken by the City

Considerable improvements in air quality were noted soon after the political transition and implementation of shock therapy based on the Balcerowicz Plan at the end of 1989. Economic restructuring and technological changes were started, and many plants such as iron foundries and cement works were shut down. In 1991, PM emissions from industrial plants and municipal installations totalled 35,800 tonnes, but this was a 35% decrease compared to 1990. Gaseous emissions amounted to 202,100 tonnes, a decrease of 47% compared to 1990. In 1993, PM emissions decreased by 5.8% and gaseous emissions by 5.2% y/y, and the downward trend continued in the following years.

Elimination of low-stack emission sources was a focus of the municipal actions supported in 1992 by the US Department of Energy and US Agency for International Development to assist with the reduction of air pollution caused by domestic sources, with a minimum increase in heating costs. This was to be achieved, e.g., through the expansion of central heat installations and district heating networks. The US Congress allocated USD 20 million to Kraków for this purpose.

AGH University of Science and Technology drew up an expert study on the environmental damage caused by HTS. In 1991, based on an agreement between the City Hall, HTS and TüV Essen, an environmental protection programme involving the modernisation and restructuring of HTS was developed. The Małopolska regional government issued a decision on permissible emissions of air pollutants, which forced HTS to achieve the intended modernisation results by 1996 while limiting steel production to 2.5 million tonnes per year. A monitoring network was also set up with financial assistance from the US EPA.

Repair and modernisation activities were carried out on a large scale at HTS and power plants, including the commissioning of electrostatic precipitators, dedusting systems and flue gas conditioning installations. Environmentally friendly measures were implemented increasingly often in other industrial and power plants as well as at municipal facilities. Coal-fired boilers in industrial plants and municipal and cooperative housing estates were systematically decommissioned. Efforts were also made to phase out individual solid fuel-fired stoves by switching households from coal to gas or connecting them to the district heating network.

From 1993, an important measure was applied which was the possibility of detaining investment projects that breached the applicable environmental requirements by the municipal authorities.

In 1996, air quality was improved by a 46% reduction in CO emissions from HTS, which was caused both by the decline in steel production and a change in the CO emission factor of blast furnace heaters. Owing to the technological changes introduced at HTS and the Kraków CHP plant (ECK, Figure 1), and the expansion of the district heating network, SO_2 emissions were reduced by approximately 12% y/y.

In 1997, the programme for the phasing out of low-stack emission sources was completed which mainly meant the decommissioning of local boiler plants using solid fuels (coal, coke). The municipality of Kraków also subsidised the elimination of many domestic coal-fired stoves, which were being replaced by gas appliances.

In 1998, although modernisation was underway and production levels were reduced, HTS was still among the 80 most polluting plants nationwide. However, a steady decrease was recorded in PM and gaseous emissions compared to previous years due to a reduction in emissions from large industrial and power generation facilities. The amount of pollutants emitted into the air was largely influenced by the increasing environmental awareness, changes in technological processes and the plants' compliance with their obligations to install pollution-reducing devices and maintain them in good technical condition.

After 2000, measures to improve air quality in Kraków were also influenced by the policies pursued at the regional level. In 2002, the regional government started the Air Quality Remediation Programme. In 2005, due to identified breaches of permissible levels of PM10 and NO_2, the regulation on formulating the air protection programme for the city of Kraków was issued. The programme defined the scope of measures, the implementation deadlines, costs, and financing sources assigned to individual tasks. Specific responsibilities in this regard were allocated to the Mayor of Kraków, companies within the Nowa Huta Economic Zone, owners and managers of industrial plants, and carriers providing transport services in the city. The programme assumed that to improve air quality in Kraków, it was necessary to reduce low-stack emissions (by eliminating household boilers and expanding the district heating network) as well as transport emissions (by developing a traffic management system and bicycle infrastructure, modernising bus fleets, renovation, and wet cleaning of streets).

At the same time, according to the Minister of Economy ordinances, the required share of electrical energy produced from RES in the total amount of energy supplied to end-users has grown every year, from 3,1% in 2005 to 20% in 2020.

In 2011, the Kraków City Council adopted the Low-stack Emission Limitation Programme [52]. The main assumption was that targeted subsidies would be provided for the permanent replacement of heating sources based on solid fuels with low-emission installations including RES such as solar thermal collectors and heat pumps. The subsidy covered purchase and installation costs. Both individuals and small businesses could benefit from the programme. It was updated in 2014 and 2015, and the outcomes are shown in Table 1.

Table 1. The effects of the implementation of the Low-stack Emission Limitation Programme [52] for the city of Krakow 2012–2019 (based on the State of the City Reports 2012–2019 [48]). Pcs., number of installations. PLN, approximately EUR 0.24 (2012)–0.23 (2019).

	2012	2013	2014	2015	2016	2017	2018	2019
Liquidated coal furnaces (pcs.)	375	1591	1320	1156	2002	3368	2456	2689
Liquidated coal boilers (pcs.)	16	255	878	1159	2240	2703	1477	1497
Assembly of RES installations (pcs.)	130	1	313	73	152	344	467	164
Expenditure amount (mln PLN)	2.1	14.0	35.8	36.4	64.9	85.9	50.7	34.7

In 2013, the Regional Council of Małopolska updated the Air Quality Remediation Programme. The types of fuels permitted for heating and hot water were specified. The fuels admitted include gaseous and liquid hydrocarbons, with the exclusion of heavy fuel oil. The resolution was applied to new constructions from 2013 and to all buildings from 2018. The replacement of all installations powered by prohibited fuels was fully financed from public funds if the new heat sources met the specified criteria or were powered by RES.

Subsequently, similar measures are being applied in 14 communes around Kraków, belonging to the Kraków Metropolis Association. Based on the experience of Krakow, some of the municipalities have tried to go further than Krakow in promoting and supporting RES when replacing old installations, focusing primarily on solutions based on solar thermal collectors, heat pumps, and photovoltaics.

Dedicated promotional and educational campaigns conducted by the City of Kraków and Kraków Metropolis Association contributed to the Air Quality Programme's success. In 2016, a record number of applications (7300) were submitted. This was supported by two "Say yes to clean air" campaigns aimed at encouraging residents to replace old installations and to obtain information on obstacles that prevented them from submitting subsidy applications. The campaign reached out to residents through various media: radio, press, television, the Internet, leaflets, posters, and films shown on public transport. In 2017, the council adopted a resolution on the total prohibition on burning solid fuels in Kraków from 1 September 2019.

3.3. Municipal Development Strategies

In Kraków's 1999 Development Strategy [53], the term "RES" was not used. Instead, the term "environmentally friendly/green" appeared in the context of power generation and the supply of heat and electricity that "meet the city's environmental requirements".

Objectives in the combined fields of energy and environmental protection were mainly related to air quality issues.

In Kraków's 2005 Development Strategy [54], in contrast to the 1999 document, "environmental protection" was understood not just as a concept associated with positive environmental impact or the absence of negative one; it became a fully-fledged policy area for municipal authorities. Kraków's strategic vision assumed that only ensuring spatial, environmental, economic, and social balance will guarantee sustainable development.

Although the term "RES" still was not used in the 2005 document, the development of geothermal energy sources was indicated as a strategic direction. The use of geothermal energy was meant, inter alia, to reduce air pollution related to the production of electricity, heating, and hot water. Kraków was to become a competitive and modern city in economic terms by embracing, among other things, the environmentally friendly geothermal energy technology, which is competitive and clean vis-à-vis traditional technologies. Kraków, as an important European centre of knowledge, was to initiate closer cooperation between its universities and the municipal district heating company to design and commissioning a geothermal plant. The plant did not materialise, although at that time geothermal energy could have appeared to be a promising RES, considering the successful development of the geothermal installations in the nearby sub-region of Podhale.

3.4. Recent Strategic Documents

The most recent package of strategic documents adopted by the City of Kraków demonstrates that the municipality finally recognised the potential of RES and integrates their use into its objectives. In 2015, the Low-Carbon Economy Plan [49] was adopted. It includes measures aimed at reducing GHG emissions, improving air quality and cutting low-stack emissions by reducing energy consumption, improving energy efficiency, and increasing the use of low-carbon energy sources. The Plan was also intended to contribute to Kraków's smart growth strategy within the framework of the Smart City concept. The strategic goal was a 20% reduction of GHG emissions by 2020 and 25% by 2030 in comparison to 1995 levels while maintaining unchanged the rate of socio-economic development. Specific goals included 10% energy efficiency improvement by 2020 and 15% by 2030 to the base year 2013 and an increase in the share of RES in the municipal energy mix to 2.3% by 2020 and 3.5% by 2030. In the first version of the document, the plan referred to the horizontal objective of the Europe 2020 strategy, while in subsequent updates it was integrated with the vision for the city's development presented in the update of the Kraków's Development Strategy 2030 [50].

The priorities of the Development Strategy include improving the quality of the environment and primarily air quality, the adjustment to climate policy directions, especially for the reduction of emissions and improving energy efficiency. In the SWOT analysis, the development and increasing popularity of RES-based technologies are mentioned among the opportunities. At the same time, the weaknesses include the low share of RES in the energy mix. The strategy does not indicate specific types of RES that should be promoted. However, the Low-Carbon Economy Plan and Kraków's Development Strategy 2030 were the first documents that integrated the policies for the reduction of air pollution and GHG emissions.

Following that, in 2020, the RES Development Programme in the Municipality of Kraków (RESDP) was adopted [51]. It contains subsidies for local RES installations including ground source heat pumps, solar thermal collectors, and PV installations in residential buildings. Integration also took place in the organizational sphere: the municipal Department for Air Quality became the administrator of RESDP funds, which helps to effectively pursue both the strategic goals of the local environmental policy: the further air quality improvement and climate mitigation that is considered by the municipality the main challenge for the next three decades. The local government has set the goal of achieving the climate neutrality of the city by 2050.

4. Discussion

Counteracting high levels of air pollution has been a priority in Kraków for decades. Pollution has been a legacy of the past economic system, but it still determines city policy. The road towards achieving acceptable air quality has been challenging and at each stage the municipality tried to select measures that were relevant and commensurate with its capabilities.

In the early 1990s, main measures focused on reducing emissions from industrial and municipal facilities. Those were restructured and equipped with cleaner technologies. Subsequently, the problem of low-stack emissions was tackled by the gradual elimination of coal-fired stoves and boilers, development of the district heating network and promotion of cleaner individual solutions, which at that time included gaseous fuels. After 2000, RES began to be recognised as a strategic solution and there was a hope that geothermal technology could be a viable means. However, it was not until 2011 that the Low-Stack Emission Limitation Programme [52] gave city residents and businesses a real opportunity to integrate RES in their heating systems.

Air quality in Kraków has been steadily improving, although pollution still exceeded permissible levels. Kraków became known as one of the most polluted cities in Europe in terms of air quality. Ultimately, systematic measures including high subsidies for residents and finally the introduction of a blanket prohibition on burning solid fuels in 2019 brought tangible results.

Currently, RES are being actively promoted in Kraków as an effective and feasible means of both low-stack and GHG emissions reduction, which is reflected in the Kraków's Development Strategy 2030 [50], Low-Carbon Economy Plan [49], and RES Development Programme (RESDP).

The review of the annual State of the City Reports, as well as historical and current strategic documents, demonstrates that RES have been included in the city's environmental policy but not as a priority but one of the means to improve air quality. The city declares that it will achieve a 3.5% share of RES in the energy mix by 2030. This may appear modest, compared to some cities that aim for 100% renewable energy and zero carbon emissions, or EU targets for transition to a low-carbon economy. However, given the amount of time and money already spent on recovering from the environmental crisis, the level assumed seems a conservative but realistic one. The challenge for the coming years is to sustain the downward trend in pollution levels, and RES will provide an increasingly effective solution to support this policy.

Kraków is in a moderately sunny zone. The amount of solar radiation energy per year is 962.2 kWh/m^2, with an average of 1500 hours of insolation per year. Solar radiation is unevenly distributed over the annual cycle: about 80% of the total annual insolation falls during the six months of the spring-summer season. Conditions in the city are unfavourable to the use of wind energy due to its location, low energy potential and limited open land resources. The usable wind energy resource is 250–500 kWh/m^2*year at a height of 10 m and 500–750 kWh/m^2*year at a height of 30 m in the open area. Hydro energy is generated in Kraków by small hydroelectric power stations constructed on the Vistula water stages Dąbie (3.0 MW), Przewóz (4.0 MW) and Kościuszko (3.1 MW). There are three CHP installations using biogas: at Barycz municipal landfill (1.3 MWe, 1.9 MWt), Kujawy sewage treatment plant (0.538 MWe, 0.887 MWt) and Płaszów sewage treatment plant (1.6 MWe, 2.4 MWt). Sewage sludge from Kujawy and Płaszów is incinerated at a thermal waste disposal facility [49]. The municipal thermal waste treatment plant has a RES certificate and installed capacity of 16.9 MW.

Considering the above, it must be concluded that due to its natural conditions the city lacks a significant potential for the further development of big RES installations. Improvement of waste management may be the only promising option. Thus, RES utilisation in Kraków is possible primarily at the civic energy level and this is the field where the city can influence the implementation of the relevant technologies.

The RESDP subsidy program [51] appeared successful. In the first call, nearly 1900 applications were received, with a value of over PLN 29 million. This was 2.6 times more than was reserved for the program in 2020. In effect, 692 partly subsidised RES installations were completed in 2020. In 2021, the pool of subsidies increases because the interest in PV installations has been rocketing. Since 2014, 3585 PV micro-installations have been connected in the city, of which 2456 (68.5%) only in 2020 [55] (Figure 4).

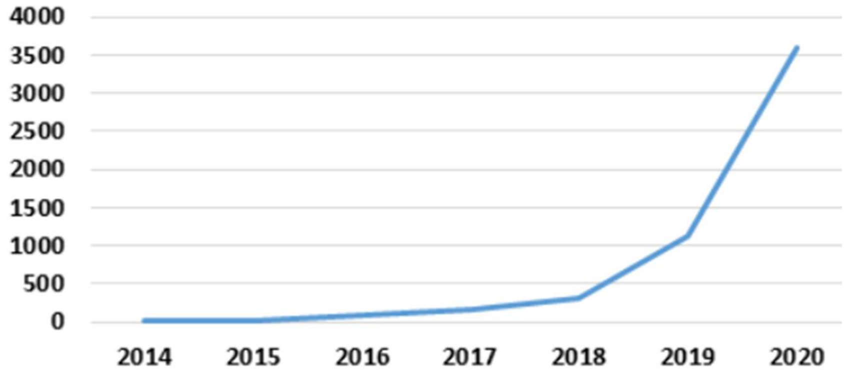

Figure 4. Number of PV installations connected in the City of Kraków, based on data from Tauron Dystrybucja Co. [55].

Moreover, an upward trend in the average power of installed household PV systems is observed from 5.135 kWh in 2019 to 5.458 kWh in 2020 [56]. This proves that this type of RES has the potential to provide an increasingly effective solution to support environmental policy. The implementation of PV micro-installations on all 563,700 single-family buildings in the Małopolska region has an estimated potential of CO2 emissions reduction by more than 26% of the 2021 level [56].

This article does not analyse separately municipal RES investments in public buildings, but it should be noted that the city systematically implements many projects in this area. Another quasi-related field is electromobility and Kraków is one of the Poland and EU leaders of transition towards low- and zero-emission public transportation. Combined low-emission policies result in the general decreasing tendency of annual air pollutant contents, confirmed by independent research [57].

The assessment of the city's RES policy must also consider socio-economic conditions. Even the most ambitious programmes could not be implemented without the participation of their beneficiaries, i.e., residents and entrepreneurs. The Low-Stack Emission Limitation Programme has been successful owing to an intensive promotional and subsidy campaign, but the main motivation for replacing household heating systems was the prohibition on burning solid fuels introduced in 2019. The "carrot or stick" approach appeared to be effective, although it must be noted that the most resolute actions of the authorities resulted from the growing pressure from a civic society organized around the "Smog Alert" social movement.

As part of the campaign to eliminate sources of low-stack emissions, the energy transformation of Kraków households might have taken different directions—the heating installations replacement programme was based on a list of environmentally friendly alternatives which included RES but also gaseous fuels. This gave households a technological and economic choice, which then determined the limited scale for RES development as, until recently, a costlier solution. Furthermore, as a result of the ban on the use of solid fuels, the biomass thus far eagerly burned in fireplaces has been eliminated—a source of renewable energy but extremely harmful due to high PM emissions.

5. Conclusions

In this review, reports and strategic papers have been analysed to investigate how the activities of local and regional governments of Krakow translated into the state of the environment, to what extent they included RES in their environmental policies and what were the results of those policies. Reports authored by the Kraków City Hall may be subjective in their assessment of city functioning. Strategic documents should, by their very nature, be ambitious and might be overly optimistic in their assumptions and objectives. Only in the long run, there is a chance to assess the dynamics of change; thus, we decided to consider a wide timespan of functioning different policies and their results. Therefore, this article should be treated as a broad, preliminary study that provides a basis for further research on the evaluation of RES inclusion in municipal policies of Kraków.

Further studies should take into account other areas significantly linked to RES implementation in municipal policies such as spatial planning, buildings, electricity generation, and electromobility. Subsequently, cross-analyses between environmental and other policies are required to transdisciplinary evaluate RES inclusion in local policies.

This article may provide material for benchmarking analyses for other cities where the level of RES implementation in strategic areas is assessed. Today, many scholarly papers propose ambitious approaches to the energy transition, but a zero-carbon economy with a 100% share of RES will not be soon an attainable goal everywhere, especially in cities such as Kraków that lack the natural potential for the large-scale RES development, and which had had to undertake transitional reforms in multiple areas ranging from the economy to the environment. Our review confirms that for almost three decades Kraków was an example of moderate inclusion of RES in municipal policy, which might be however adequate to the needs and intended goals at that time. The priority had been to improve local air quality and not to decrease CO_2 emissions. Gradually, when it appeared more economically feasible, RES have found their place among the means to effectively combat low-stack emissions, particularly within the framework of civic energy.

After the introduction of a complete ban on the use of solid fuels in 2017, the policy target has shifted from low-emission to zero-emission. That triggered the change towards RES as a viable means to tackle both local (air pollution) and global (GHG emission) environmental problems. That was reflected in the RESDP program. The success of that programme measured in the rocketing popularity of PV installations shows that RES development depends to a large extent on political decisions. Financial support for prosumers in the form of subsidies for the new solar systems and heat pumps resulted in a rocketing number of RES installations and power generation from solar PV in the city.

The hypothesis proposed in Section 2 of this article has been confirmed. The integration of local air quality targets with global decarbonisation goals launched a dedicated subsidy stream for RES installations. In practice, it basically meant a change in the policy of subsidizing the modernization of domestic heating systems. Subsidies for the installation of low-emission heating systems, e.g., gas-fired boilers, have been replaced by subsidies for the installation of zero-emission heating systems, mainly powered by photovoltaics. It was a pivotal shift in municipal environmental policy that significantly improved the economic feasibility of domestic RES and in the scale of the city made them a viable means to decrease both low-stack emissions and CO_2 emissions.

The final conclusion would be a policy recommendation for cities with similar problems as Kraków: (1) The municipal RES policy must consider local physiography as well as socio-economic conditions, participation of civic society, and include intensive promotional and subsidy campaign. (2) A policy mix should include both carrot and stick policies. (3) If the local government provides subsidies for the modernisation of heating systems, the integration of policies for clean air and climate mitigation increases the dynamics of RES development.

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