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WHAT'S NEW?

Our study addresses socioeconomic and environmental conditions on heart failure (HF) in Poland, Europe. This study, to date, is the largest of its kind considering 1.6 million hospitalizations and 8 years of observations. In our research, we look not only at the national data, but additionally, we analyze regional-level hospitalizations. The results of the provided analyses indicate that increase in regional indicators such as the higher share of physicians and healthcare expenditure, higher green areas density, higher working-age population structure, decrease in the unemployment rate and lower number of cars can cause a reduction in HF-related hospitalizations. Our study indicates that health policy measures including environmental and socioeconomic instruments may result in positive health outcomes. Additional analyzes are needed to compare the impact of socioeconomic and environmental factors against the impact of healthcare alone.

ABSTRACT

Background: Over 1.5 million people in Poland suffer from heart failure (HF). The risk of hospitalization is related to environmental, socioeconomic factors and the organization of the health care system.

Aims: The study aimed to assess the influence of environmental and socioeconomic factors on the prevalence of hospitalization for HF.

Methods: The impact of environmental and socioeconomic factors on HF hospitalizations in Poland in 2012–2019 based on the National Institute of Public Health and Central Statistical Office in Poland data and panel data regression techniques has been estimated.

Results: There were 1,618,734 HF-related hospitalizations (51.3% male; 82.6% aged >65 years). An increase in the number of physicians by 10/10000 population and healthcare expenditure of 100 PLN per capita resulted in 3.5% (–0.035; 95% confidence interval [CI], –0.06–[–0.01]; *P* = 0.002) and 3% (–0.029; 95% CI, –0.04–[–0.013]; *P* <0.001) decrease in hospitalizations, respectively. For each new outpatient healthcare facility per 10 000 population, there was a 3% (–0.031; 95% CI, –0.048–[–0.014]; *P* <0.001) decrease in hospitalizations. One percentage point increase in the proportion of green areas resulted in a 2.7% (–0.027; 95% CI, –0.042–[–0.01]; *P* = 0.049) decrease in hospitalizations. However, an increase of cars by 1000 inhabitants and a 1 percentage point increase in the unemployment rate were associated with a 6% increase in HF hospitalizations (0.064; 95% CI, 0.008–0.121; *P* = 0.026).

Conclusions: The number of HF-related hospitalizations has been increasing in the last decade. This trend is most noticeable in regions with low socioeconomic development and poor medical facilities. Our study indicates that health policy measures including environmental and socioeconomic instruments may result in positive health outcomes. Additional analyzes are needed to compare the impact of socioeconomic and environmental factors against the impact of healthcare alone.

Key words: environment, economic development, health care system, heart failure, public health policy

INTRODUCTION

The document "A New Perspective on the Health of Canadians" created by Marc Lalonde described the first holistic health determinant model and introduced the concept of health fields as four overarching categories of health determinants. The greatest influence on health was attributed to lifestyle and the living environment. A novelty was the recognition of the significant contribution of factors related to socioeconomic and psychosocial determinants, including access to health care [1]. This concept was later developed, among others, by Göran Dahlgren and Margaret Whitehead who created the rainbow model of health determinants, showing the links between biological factors and, among others, lifestyle and broadly defined socio-economic, cultural and environmental factors [2]. Since the turn of the century, the concept of socio-economic determinants of health has been one of the paradigms of the World Health Organization (WHO). WHO emphasizes shaping the new multisectoral approach to the implementation of public health policy [3].

Despite the development of knowledge in the context of holistic health determinants, primary and secondary prevention measures still are a subject of interest to the healthcare sector, while socio-environmental factors are often overlooked, although they are of great importance, particularly in the field of cardiovascular diseases (CVD) [4–6]. CVDs are the greatest threat to the health and life of the Polish population and heart failure (HF) is one of the major factors of morbidity and mortality in Poland [7]. Despite significant progress in the understanding of pathophysiology and implementation of extensive primary and secondary prevention, HF is also a significant social problem. The frequency of hospitalizations due to HF is steadily increasing and it is the main cause of hospitalization of patients over 65 years of age. Due to the aging of the population, the need for the introduction of new drugs and invasive procedures will increase [8].

The incidence and prevalence of HF show a large geographical variation, which can only be partly explained by the prevalence of classical risk factors for the development of the disease [8]. Nowadays, there is convincing evidence that environmental factors — particularly air pollution - are associated with increased cardiovascular morbidity and mortality, but there is highly limited evidence regarding the impact of socioeconomic factors. In our view, these factors are one of the key determinants of health outcomes in patients with HF. Furthermore, socioeconomic deprivation may increase vulnerability to cardiovascular complications caused by environmental factors.

The hypothesis regarding the influence of environmental and socioeconomic factors on the prevalence of HF became the basis for conducting our study. We sought the extent to which these factors are associated with the rate of HF hospitalizations. Our analysis covered over 1.6 million hospitalizations in over 8 years of follow-up.

AIM

To assess the influence of environmental and socioeconomic factors on the prevalence of hospitalizations for HF in Poland.

METHODS

Study design

We conducted retrospective analyses. We evaluated whether socioeconomic and environmental factors affect hospitalizations due to HF in Poland. The data were obtained from the National Institute of Public Health — National Institute of Hygiene in Poland and aggregated to 380 counties (NUTS4) level as the 3-year means. The data provider adopted the Polish population age structure as the standard age structure (HF hospitalization in Poland equals 1).

The set of explanatory variables included environmental and socioeconomic factors. Information on air pollutants concentrations was obtained from Chief Inspectorate for Environmental Protection. Socioeconomic variables were obtained from Central Statistical Office in Poland. Both aggregation and averaging procedures have partly done away with the problems of random fluctuations. The aforementioned factors were divided into three groups, in particular the set concerning medical care, economic conditions, and environmental. The group of medical variables consisted of medical doctors per 10 000 inhabitants, health expenditure per capita and ambulatory departments subordinate to the local government. In the group of variables describing the economic condition of regions we included gross domestic product (GDP) per capita, sold production of industry per capita, investment per capita, the share of employed in agriculture, services, working-age population share, municipal own income per capita, and finally unemployment rate. Part of these variables was aggregated from the municipality level to counties, the rest of them were already available on this level.

The last group of variables was related to the environment in the studied areas. It was defined by wastewater treatment plants, industrial wastewater discharged, bicycle tracks density, forests density, protected area density, vehicles per 1000 inhabitants, population density and concentration of air pollutants such as particulate matter with a diameter of 2.5 μm or less ($PM_{2.5}$), 10 μm or less (PM_{10}) and nitrogen dioxide (NO_2). All environment variables except air quality were aggregated from the municipality level to counties. Air pollution variables were analyzed at the voivodeship level.

Statistical analysis

The distribution of the variables was assessed with the Shapiro-Wilk test. Data are expressed as means and standard deviations (SD). Statistical significance between variables was determined using the Student T-test. Panel regression methods were used in the statistical analysis (mainly fixed and random effects methods) as well as the generalized least squares method (GLS) [9, 10]. Parameters were estimated using three-year averages for both HF hospitalizations and three-year averages of the explanatory variables. Not only were the parameters of the equations estimated, but also, we assessed the marginal effects associated with the influence of the mentioned factors on HF. Those semi-elasticities are interpreted as the percentage change in standardized rates of HF hospitalization per unit change in the explanatory variables ceteris paribus.

To get robust estimates and sensitivity analyses the elasticities were estimated independently for subgroups of variables and additionally in sub-periods separately. Results are presented as marginal effects (semi-elasticities) and 95% confidence intervals (95% CI).

The threshold of statistical significance for all tests was set at $P<0.05$. All analyses were performed using Stata Statistical Software, (StataCorp, 2022, version 17, TX, US).

The study was financed from the funds of the National Science Center granted under the contract number UMO-2021/41/B/NZ7/03716 and registered at ClinicalTrials.gov (NCT05198492).

RESULTS

We analyzed 1 618 734 hospitalizations due to HF in Poland in 2012–2019 (51% males). There was a significant predominance of people aged 65 and over (82% of all hospital admissions due to HF, $P<0.001$).

Data on hospitalizations due to HF per 100 000 inhabitants on average per year in the analyzed period 2012–2019 is presented in Figure 1. The spread of HF cases was enormous among Polish voivodeships (NUT2 level). The lowest average values of 300 hospitalizations per 100 000 inhabitants were noted in Pomorskie voivodeship, while the highest (over 700 admissions) were in Podkarpackie, Swietokrzyskie, Lubelskie and Lodzkie. Moreover, the dynamics concerning changes in HF hospitalizations in 2012–2019 also differed. In all voivodeships, HF hospitalizations ratios per 100 000 inhabitants increased, while the highest rise was observed in Podlaskie Voivodeship, where the registered growth rate was 102%.

The standardized hospitalization rates due to HF can be described by a dissimilar smaller range (from 1.17 to 3.87) as presented on the counties distribution map (Figure 2). On average the highest coefficients were noted in districts of eastern Poland, mainly in Podkarpackie and Lubelskie voivodeships, while the lowest were in Pomorskie, Zachodniopomorskie and Dolnoslaskie. The average value of the ratios in the studied sub-periods decreased from 1.12 to 1.10, and this drop was complemented by a decrease in the regional variation (Figure 2).

Most economic variables were highly varied in particular regions in Poland. Working age population share stands out against them. The descriptive statistics for these variables are presented in Table 1. An increase in the number of physicians by 10/10000 population and healthcare expenditure of 100 PLN per capita resulted in a 3.5% (–0.035; 95% CI, –0.06–[–0.01]; $P = 0.002$) and a 3% (-0.029, 95%CI -0.04 – -0.013, P<0.001) decrease in hospitalizations, respectively. For each new ambulatory healthcare facility per 10000 population, there was a 3% (–0.031; 95% CI, –0.048–[–0.014]; $P < 0.001$) decrease in hospitalization. One percentage point increase in the proportion of green areas and increase of working age population resulted in a 2.7% (–0.027; 95% CI, –0.042–[–0.01]; $P = 0.049$) and 1.5% (–0.015; 95% CI, –0.033–[–0.003]; $P = 0.01$) decrease in hospitalizations. However, an increase of vehicles by 1000 inhabitants and 1 percentage point in the unemployment rate were associated with a 6% increase in HF hospitalizations (0.064; 95% CI, 0.008–0.121; $P = 0.026$) and 1% (0.008; 95% CI, 0.001–0.011; $P = 0.04$) increase in hospitalization, respectively (Figure 3). Air pollution appears to be an important determinant of hospitalizations due to HF. An increase in the $PM_{2.5}$ and P_{10} by 10 µg/m^3 at voivodeship resulted in county increase in HF hospitalizations by 7.5% (0.075; 95% CI, 0.013–0.137; $P = 0.017$) and 6% (0.060; 95% CI, 0.012–0.108; $P = 0.015$).

DISCUSSION

To our knowledge, this is the first national wide study that focuses on the impact of socioeconomic and environmental factors such as air pollution on HF. Many previous studies reported a correlation between socioeconomic status and CVD risk [11, 12]. Variation in the burden of HF is likely also due to factors other than traditional. Among them there are environmental and socioeconomic factors, which are confirmed in our analysis.

The main findings indicate that environmental factors affect the frequency of hospitalization due to HF. Residents of areas with high environmental pollution such as density of vehicles and forests, air pollution, and low greenness were far more likely to experience HF-related hospitalization. On the other hand, patients with low socioeconomic status characterized not only by a lower number of physicians and lower healthcare facilities density or healthcare expenditures were far more likely to experience hospital admission due to HF.

As our results show, despite progress made in pharmacological therapy in the last decade, HF-related hospitalizations are on the rise in Poland, especially in Podlaskie voivodeship. It is related to an aging society, higher prevalence of comorbidities, lack of properly organized pre-hospital care and improvement in the treatment of acute cardiovascular diseases [13]. Our study revealed that an increase in the number of medical doctors, healthcare expenditure and healthcare facilities were associated with a decrease in hospitalizations due to HF. In the available literature, lower physician concentration was associated with a greater chance of readmission and a higher mortality rate due to cardiovascular disease

(CVD) [14–16]. ESC Guidelines emphasize that self-management programs are extremely important in the therapy of HF as they reduce the risk of hospitalization or death [17]. Several studies show the great effectiveness of patient education in reducing readmission rates and mortality [18, 19]. The experts from the Polish Cardiac Society point out that to this date there is no such program in Poland [20]. The latest ESC Guidelines on HF, experts' opinion and results such as ours, should prompt the government to implement systemic changes such as increasing financial funding for healthcare in poverty-stricken areas, establishing a national registry of HF and introducing self-management programs as health insurance does not mean equal access to the health care system.

Living in areas with a higher share of surrounding residential greenness has been proven beneficiary to peoples' health [21, 22]. There are multiple reasons to explain this phenomenon. For instance, residents of these neighborhoods tend to do more physical activity [23]. Moreover, living in green spaces might improve mental health and reduce detrimental environmental exposures such as air pollutants, noise and heat [24, 25]. In our study, we observed a connection between the share of green areas and a decrease in HF-related hospitalizations [26]. Plans et al. [27] showed that the density of green spaces had a positive impact on cardiovascular risk factors, but only in a female population.

As our study revealed, risk factor that significantly influences the increased number of HF-related hospitalizations is the number of vehicles per 1000 inhabitants. Air pollution is a well-established trigger for CVD incidence. Interestingly enough, vehicles' exhaust is not the only source of car smog, as it is commonly believed. The contribution of tires, brakes and road deposits to overall particle emission increases each year and has become a real problem [28]. Shah et al. in their meta-analysis suggest that air pollutants such as PMs, carbon monoxide, sulfur dioxide and NO_2 have a harmful impact on the circulatory system and increase morbidity and mortality due to HF [29]. Another recent systematic review based on robust evidence indicates chronic exposure to the abovementioned air pollutants on cardiovascular morbidity and mortality [30]. More recent studies seem to agree with the aforementioned systemic review [31, 32]. Moreover, an experimental study designed by Phipps et al. showed that exposure to traffic-generated smog might cause increased activity of the renin-angiotensin system leading to CVD and obesity [33]. In light of this information, we believe that implementing transport infrastructure layouts and transport policies that mitigate air pollution should become a top priority. For the time being, patients, especially those from a high-risk group, need to follow preventive measures.

When analyzing the role of health care structure in the treatment of HF, it is impossible to ignore the importance of palliative care (PC) and its impact on patients' life. In Poland, only 1.5% of patients with reported contact with the PC were referred due to CVD in 2019 [34]. Sobański et al. emphasize the role of PC in pain and depression management in patients with HF, which contributes not only to improvement in quality of life but also to better prognosis and reduced the readmission rate in patients with HF [36, 37].

Our paper shows that in the group of economic and sociological factors such as unemployment rate and agriculture share were found to be significant in affecting HF-related hospitalizations. The unemployment rate impact is probably due to the fact that this rate blandly characterizes the poverty profile of the selected studied regions. Its high value is closely related to the occurrence of more diseases in the area [38]. The number of people employed in agriculture sheds light on the characteristics of the economic structure and specialization. Rural areas are often poorer, and thus access to health facilities is more difficult [39].

The only purely socio-demographic factor in this group is the working-age population. This indicator is directly related to the age dependency ratio and the problem of an aging population. Areas with a low working-age population tend to be less efficient due to limited human capital value. Research confirms that working-age population share and a reduction in the child dependency ratio are found to be associated with an increase in GDP per capita growth, with similarly positive effects on poverty reduction [40].

Considering all factors, public health policies should focus also on urban planning interventions to increase green space coverage, reduce traffic-related air pollution and on the sustainable development of a country.

Limitations

There are several limitations to our study. First of all, our research does not take into account some of the most common medical factors affecting the frequency of hospitalization due to HF Secondly, we were unable to assess the individual exposure of patients to environmental factors since we have no information on the exact residence of patients. We cannot separate analyzed hospitalizations into those caused by HF de novo and acute decompensated HF. In our study, the analyzed period is the years 2012–2019, it would certainly be very interesting to assess the impact of the COVID-19 pandemic on this issue, as some studies show that the SARS-CoV-2 virus increased the risk of myocarditis, acute and chronic HF, however, there is no data on HF-related hospitalizations in Poland in 2020–2022 yet [41, 42].

CONCLUSIONS

The number of HF-related hospitalizations has been increasing in the last decade. This trend is most noticeable in regions with low socioeconomic development and poor medical facilities.

Our study indicates that health policy measures including environmental and socioeconomic instruments may result in positive health outcomes. Additional analyzes are needed to compare the impact of socioeconomic and environmental factors against the impact of healthcare alone.

Article information

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Table 1. Explanatory variables descriptive statistics in Polish counties in 2012–2019

Variable	**Mean in Poland**	**County minimum**	**County maximum**	**Coefficient of dispersion**	**Coefficient of variation**
Health care services					
Physicians, 10 per 10^4 inhabitants	38.54	2.00	202.6	0.72	0.34
Health expenditure per capita, 100 PLN per capita per year	20.95	6.23	194.6	0.64	0.24
Ambulatory healthcare facility, per 10^4 inhabitants	4.70	1.93	12.3	0.33	0.2
Socio-economic conditions					
Gross domestic product at constant prices, PLN per capita	30 626	13 579	130 731	0.39	0.21
Sold production of industry, PLN per capita	22 779	0.00	207 222	0.95	0.6
Investment, PLN per capita	3 205	176	27 583	0.94	0.49
Unemployment, %	3.7	2.7	16	0.94	0.49
Employment in agriculture, % of total employment	11.49	0.36	79.06	0.69	0.58
Employment in services, % of total employment	57.97	15.2	86.8	0.35	0.24
Municipal own income, PLN per capita	1347	0.00	7586	0.65	0.27
Environmental conditions					
Industrial wastewater discharged, persons per km^2	1.21	0.00	194	9.6	2.94
Bicycle tracks density, $km/10{,}000km^2$	716	0.00	1700	1.48	1.4
Forests density, %	29.4	0.00	72.2	0.92	0.84
Protected area density, ha per km^2	0.30	0.00	1.00	0.74	0.58
Vehicles, per 1000 inhabitants	576	187	1042	0.14	0.09
Population density, persons per km^2	123	17.7	3899.3	1.46	0.88

Table 2. Mean concentration of air pollutants in 16 voivodeships in years 2012–2019

	Air pollutant	**Mean yearly concentration, μg/m^3**								**Mean 8-year concentration, μg/m^3**
		2012	2013	2014	2015	2016	2017	2018	2019	
Dolnoslaskie	$PM_{2.5}$ (SD)	25.52 (5.2)	25 (4.4)	23.15 (4.5)	21.28 (4.3)	22.34 (4)	21.21 (1.1)	21.65 (1.4)	17.34 (2.3)	22.19 (2.55)
	PM_{10} (SD)	31.7 (16.8)	28.43 (8.8)	34.21 (11.3)	32.73 (9.9)	30.85 (7.6)	30.53 (3)	31.02 (4.9)	25.35 (2.8)	30.6 (2.7)
	NO_2 (SD)	14.14 (11.8)	13.93 (11.7)	16.27 (11.7)	16.83 (11.5)	16.21 (10.9)	16.02 (10.3)	15.9 (9.8)	15.36 (8.6)	15.58 (1.04)
Kujawsko-pomorskie	$PM_{2.5}$ (SD)	17.74 (3.7)	17.08 (4.3)	21.47 (2.1)	20.01 (2.8)	19.63 (3.9)	18.94 (3.8)	22.12 (3.9)	17.55 (4)	19.3 (1.85)
	PM_{10} (SD)	29.54 (8)	28.33 (8.4)	33.02 (4.7)	31.53 (4.4)	29.5 (5.3)	29.53 (5.2)	31.27 (3.9)	25.43 (3.1)	29.75 (2.31)
	NO_2 (SD)	16.83 (9.8)	18.89 (8.4)	16.33 (8.7)	17.34 (8.3)	16.69 (7.4)	16.31 (7.9)	16.79 (7.9)	14.44 (6.3)	16.69 (1.24)
Lubelskie	$PM_{2.5}$ (SD)	21.3 (2.5)	21.41 (2.5)	23.9 (4.2)	25.39 (4.3)	23.14 (2.8)	23.15 (2.3)	22.5 (2.9)	18.1 (2.7)	22.36 (2.17)
	PM_{10} (SD)	30.77 (5.4)	29.86 (3.2)	31.86 (3.1)	32.58 (4.4)	28.53 (2.6)	30.43 (3.4)	28.86 (3.3)	23.83 (2.9)	29.6 (2.72)
	NO_2 (SD)	15.73 (5.2)	15.19 (5)	13.75 (6)	13.24 (6.6)	12.45 (6.1)	12.19 (6.8)	12.85 (7.4)	11.82 (4.5)	13.39 (1.41)
Lubuskie	$PM_{2.5}$ (SD)	19.67 (4.8)	20.67 (4.5)	21.31 (4.9)	19.45 (2.2)	19.96 (1.8)	19.88 (2.3)	19.54 (2.8)	16.16 (3.6)	19.6 (1.51)
	PM_{10} (SD)	27.59 (9.1)	26.38 (7.9)	29.16 (6.3)	26.03 (5.1)	27.84 (4.1)	26.44 (5.5)	28.46 (5.1)	23.07 (3.5)	26.88 (1.89)
	NO_2 (SD)	13.12 (7.1)	13.08 (6.6)	13.32 (7.4)	13.65 (7.1)	13.46 (6.9)	14.03 (6.3)	13.99 (6.3)	12.21 (5.6)	13.36 (0.59)
Lodzkie	$PM_{2.5}$ (SD)	29.27 (9.2)	27.74 (6.8)	27.68 (8.1)	25.11 (4.7)	23.33 (3.9)	26.63 (4.7)	25.67 (3.6)	22.18 (3.5)	25.95 (2.38)
	PM_{10} (SD)	40.66 (9.3)	40.23 (7.9)	39.47 (7.6)	35.31 (8.1)	36.51 (5.9)	36.7 (4.8)	35.6 (4.4)	30.44 (3.8)	36.86 (3.35)
	NO_2 (SD)	19.98 (14.1)	19.23 (13.4)	19.81 (12.2)	20.57 (12.3)	21.3 (12)	19.9 (12.4)	19.55 (12.6)	17.16 (12.5)	19.69 (1.2)

Malopolskie	$PM_{2.5}$ (SD)	38.35 (4.7)	32.94 (5.6)	31.55 (6.6)	27.64 (6.2)	29.3 (3.5)	30.31 (4.9)	28.59 (5.5)	23.24 (3.1)	30.23 (4.38)
	PM_{10} (SD)	47.83 (9.8)	43.09 (8.9)	40.02 (9.5)	42.07 (10.7)	36.31 (7.5)	39.64 (6.1)	38.78 (7)	32.38 (6.4)	40.01 (4.6)
	NO_2 (SD)	26.86 (14.6)	25.73 (15.8)	23.59 (14.6)	24.86 (15.7)	27.61 (13.9)	26.42 (14.1)	25.73 (14.2)	24 (14.1)	25.6 (1.38)
Mazowieckie	$PM_{2.5}$ (SD)	26.88 (2)	25.3 (3.4)	26.51 (2.5)	24.88 (1.4)	23.35 (2.4)	23.85 (3.3)	23.38 (1.6)	19.04 (2.7)	24.15 (2.47)
	PM_{10} (SD)	35.61 (4.9)	32.21 (4.6)	33.14 (4.7)	33.16 (5.1)	30.79 (5.2)	31.37 (5.9)	32.84 (6.4)	25.72 (5.3)	31.85 (2.87)
	NO_2 (SD)	21.27 (8.8)	22.67 (13.3)	21.89 (11.7)	22.85 (13)	21.26 (13.1)	20.65 (11.7)	19.8 (10.7)	18.73 (10.5)	21.15 (1.4)
Opolskie	$PM_{2.5}$ (SD)	27.01 (2.1)	27.92 (3.2)	25.86 (3.6)	22.85 (2.4)	23.28 (2.6)	23.49 (3.4)	23.08 (3.3)	18.17 (3.1)	23.98 (3.03)
	PM_{10} (SD)	36.56 (4.9)	36.38 (4.7)	37.4 (4.5)	34.07 (4)	33.14 (3.3)	33.82 (4.7)	34.11 (4.3)	27.98 (3.5)	34.19 (2.94)
	NO_2 (SD)	18.27 (4.9)	16.89 (5.6)	17.38 (4.7)	18.07 (4.9)	16.07 (4.4)	15.88 (4.4)	16.29 (4.5)	13.76 (6.7)	16.6 (1.44)
Podkarpackie	$PM_{2.5}$ (SD)	29.31 (4)	25.75 (3.2)	23.99 (1.3)	24.56 (1.7)	23.15 (1.9)	24.12 (0.9)	23.45 (1.1)	19.88 (2.8)	24.3 (2.64)
	PM_{10} (SD)	37.51 (9)	34.06 (6.7)	31.83 (3)	32.48 (3.9)	29.02 (2.6)	30.04 (4.9)	30.42 (4.6)	24.63 (3.8)	31.24 (3.79)
	NO_2 (SD)	18.36 (5)	18.63 (5.4)	14.36 (4.6)	13.56 (5.1)	12.98 (4.7)	13.24 (4.7)	12.85 (4.6)	14.94 (6.6)	14.88 (2.34)
Podlaskie	$PM_{2.5}$ (SD)	26.72 (7.1)	22.54 (6.5)	21.16 (4.7)	21.2 (5.9)	19.14 (6)	16.47 (6)	18.95 (5.3)	14.37 (5.8)	20.06 (3.77)
	PM_{10} (SD)	26.33 (4.7)	24.09 (5.7)	27.59 (4.8)	27.45 (5.2)	22.83 (3.6)	21.16 (3.7)	24.57 (3.7)	19.3 (4.1)	24.16 (2.96)
	NO_2 (SD)	10.75 (5.3)	9.49 (5.1)	10.38 (5.5)	10.27 (4.5)	9.86 (4.9)	9.83 (4.1)	10.88 (5.1)	9.73 (4.1)	10.15 (0.5)
Pomorskie	$PM_{2.5}$ (SD)	21.07 (7.9)	18.21 (10)	21.97 (8.8)	17.88 (7.5)	17.05 (8.7)	17.46 (9.1)	19.07 (6.8)	13.47 (6.1)	18.29 (2.61)
	PM_{10} (SD)	24.45 (7.2)	22.19 (6.9)	27.22 (7.4)	23.36 (6.3)	23.44 (7.8)	21.18 (4.3)	26.34 (5.2)	21.26 (4.2)	23.69 (2.21)
	NO_2 (SD)	15.58 (5.2)	14.51 (4.7)	14.38 (5)	13.75 (4.5)	13.75 (4.4)	13.57 (4.3)	15.1 (4.5)	13.33 (4.2)	14.25 (0.8)

Slaskie	$PM_{2.5}$ (SD)	33.36 (2.2)	31.69 (1.9)	31.04 (3.7)	27.65 (2.3)	27.91 (5.1)	29.48 (3.5)	29.86 (2.5)	23.51 (3.1)	29.31 (3.03)
	PM_{10} (SD)	47.58 (5.7)	43.14 (4)	43.48 (5.8)	40.3 (4.5)	38.92 (5.5)	40.75 (4.6)	40.66 (4.9)	33.38 (5.3)	41.03 (4.09)
	NO_2 (SD)	25.18 (9)	24.49 (8.9)	23.54 (10.9)	24.47 (11.8)	23 (11.2)	24.04 (11.1)	24.36 (11.1)	22.89 (11.4)	24 (0.81)
Swietokrzyskie	$PM_{2.5}$ (SD)	29.83 (7.3)	25.96 (4.4)	25.73 (4.1)	22.94 (3)	21.29 (2.8)	23.3 (4.6)	24.1 (5.2)	18.79 (2.1)	23.99 (3.31)
	PM_{10} (SD)	36.16 (8.7)	31.61 (5.7)	33.1 (6.4)	31.79 (5.6)	29.27 (4.3)	32.57 (5.7)	33.13 (5.6)	26.96 (3.9)	31.84 (2.74)
	NO_2 (SD)	23.09 (6.8)	16.93 (5.2)	13.75 (5.5)	18.06 (6)	16.7 (5.1)	13.6 (5.8)	15.78 (7.6)	16.74 (6)	16.83 (2.98)
Warminsko-mazurskie	$PM_{2.5}$ (SD)	17.09 (5.4)	15.63 (3.7)	16.9 (3.4)	16.29 (2.7)	15.01 (5.4)	16.26 (3.3)	17.71 (3.4)	13.83 (4)	16.09 (1.26)
	PM_{10} (SD)	22.7 (7)	22.7 (5.5)	24.24 (6)	24.13 (5.6)	24.99 (4.5)	24.7 (4.5)	26.99 (5.3)	19.71 (3.6)	23.76 (2.14)
	NO_2 (SD)	10.63 (5.5)	10.78 (6.4)	11.08 (6.1)	10.46 (7)	10.94 (6)	11.07 (5.1)	11.41 (4.8)	9.1 (5.7)	10.69 (0.7)
Wielkopolskie	$PM_{2.5}$ (SD)	28.42 (7)	25.97 (6.8)	27.25 (5.7)	26.51 (6.7)	26.85 (5.9)	25.28 (4)	23.75 (3.6)	20.76 (3.7)	25.61 (2.37)
	PM_{10} (SD)	32.72 (4.8)	30.94 (6)	34.34 (5.4)	32.04 (4.9)	31.02 (4.7)	29.59 (4.2)	30.86 (3.9)	26.56 (3.2)	31 (2.27)
	NO_2 (SD)	15.47 (6.1)	15.07 (11.1)	16.05 (10.9)	16.67 (7.1)	16.82 (9.6)	15.82 (8.9)	16.81 (8.7)	15.62 (4.8)	16.05 (0.66)
Zachodniopomorskie	$PM_{2.5}$ (SD)	15.87 (3.7)	15.15 (6)	19.76 (3)	16.29 (2.7)	16.36 (3.2)	17.27 (2.7)	18.28 (2.3)	14.53 (1.9)	16.71 (1.71)
	PM_{10} (SD)	24.3 (6.3)	23.9 (7.3)	26.87 (4.1)	23.9 (4.1)	23.36 (3.4)	23.6 (3.3)	25.52 (2.3)	20.78 (1.8)	24.04 (1.75)
	NO_2 (SD)	17.71 (11.7)	18.82 (11.6)	18.63 (11.3)	17.68 (7.4)	18.64 (10)	16.17 (9.3)	17.8 (9.1)	13.74 (8.1)	17.39 (1.7)

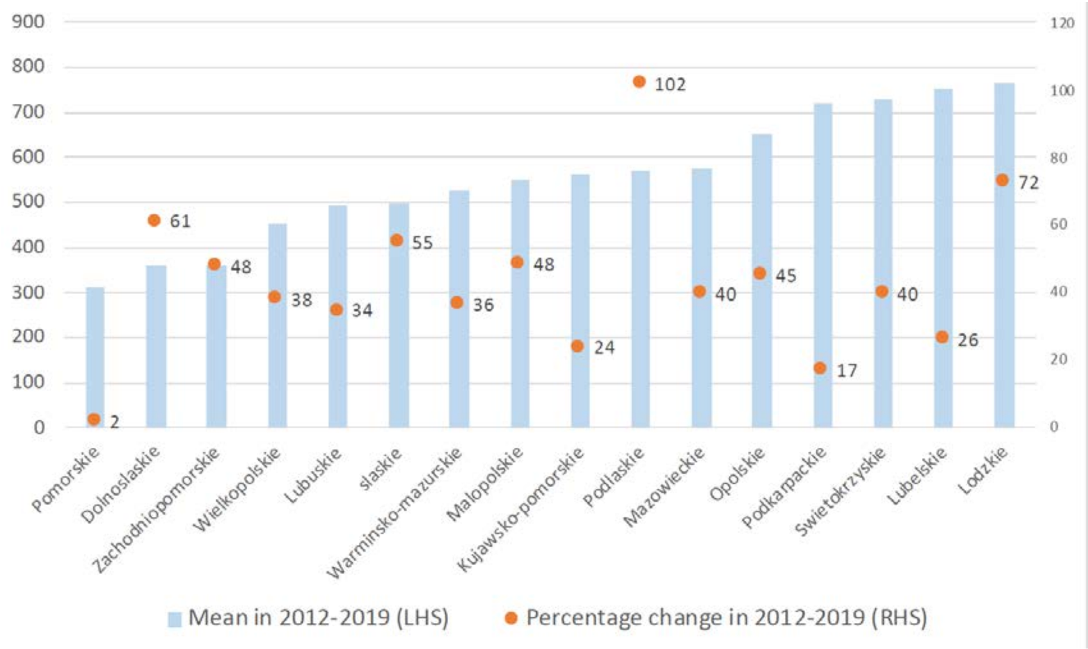

Figure 1. Hospitalizations due to heart failure per 100 000 inhabitants per year in 2012–2019 in Polish voivodeships

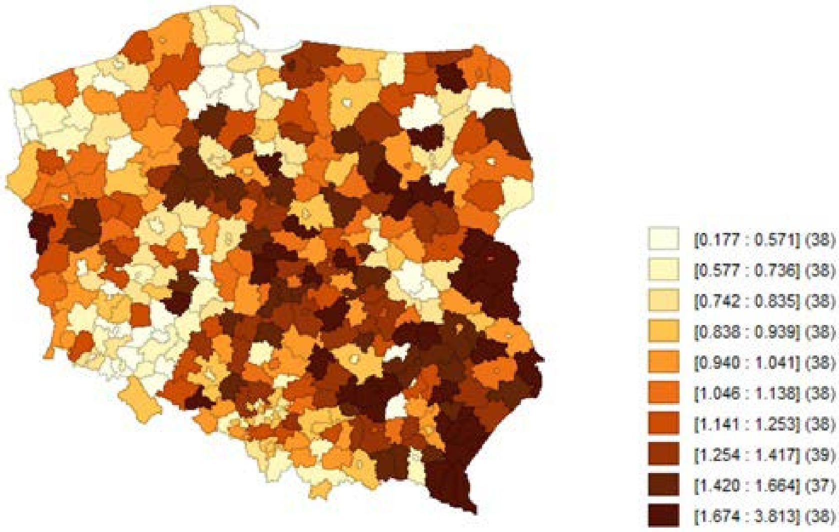

Figure 2. Standardized hospitalization ratio due to heart failure in 2012–2019 in Polish counties

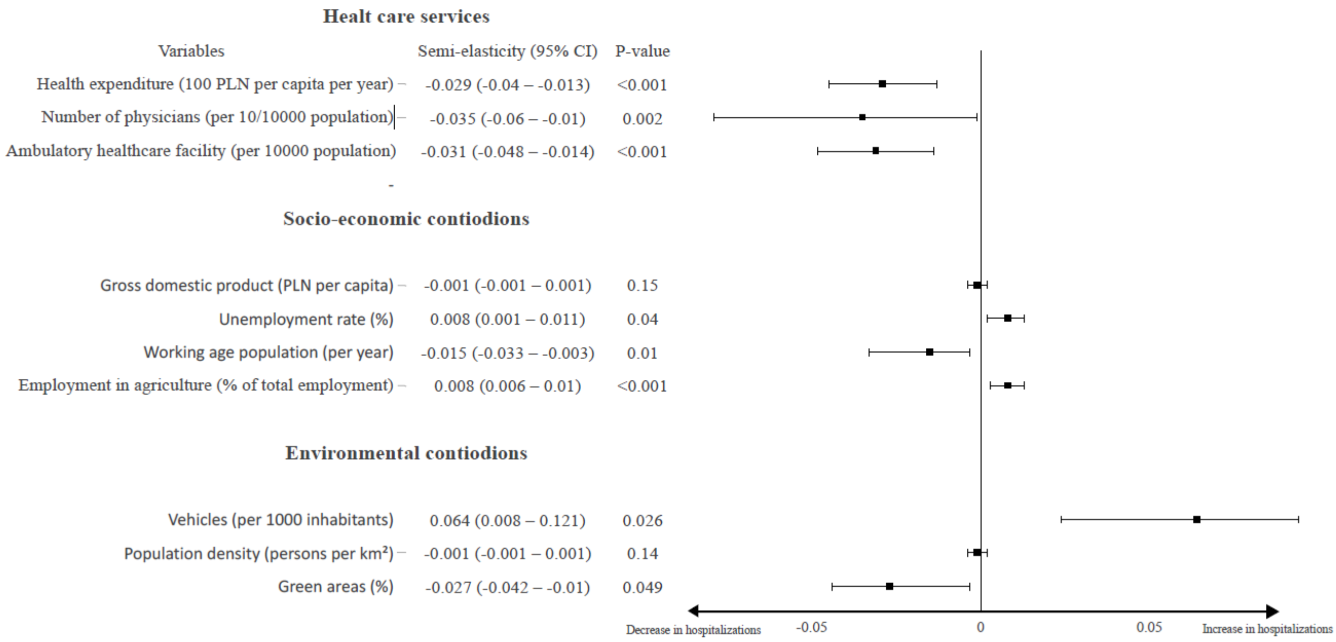

Figure 3. Effect of health care services, socio-economic conditions, and environmental conditions on hospital admissions in 2012–2019 in Poland due to heart failure. The data are presented as semi-elasticity with 95% confidence intervals (CI). On the graph was shown only variables with *P*-value less than 0.2

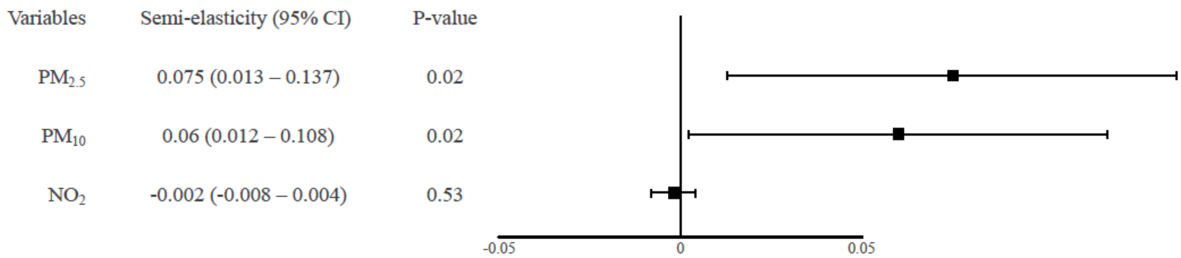

Figure 4. Effect of air pollution on hospital admissions in 2012–2019 in Poland due to heart failure. The data are aggregated to 16 voivodeships of Poland and presented as semi-elasticity with 95% confidence intervals