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THEORETICAL AND METHODOLOGICAL PROBLEMS

ENVIRONMENTAL POLICY AND MANAGEMENT

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GENERAL ENVIRONMENTAL AND SOCIAL PROBLEMS

ENVIRONMENTAL POLICY AND MANAGEMENT

POLITYKA EKOLOGICZNA I ZARZĄDZANIE ŚRODOWISKIEM

Natalia Yosipivna SHUPTAR-PORYVAIEVA • Elena Rostislavovna GUBANOVA • Natalia Mykolaivna ANDRYEYEVA • Tetiana Ivanivna SHEVCHENKO

EXAMINING OF PORTABLE BATTERIES EXTERNALITIES WITH FOCUS ON CONSUMPTION AND DISPOSAL PHASES

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ABSTRACT: Today, the problem of increasing negative environmental externalities related to waste management, especially electronic waste, which also includes used household batteries and accumulators, is becoming increasingly acute. They cause significant damage not only to the environment but also to public health when released into the environment without control. The purpose of this work is to study the environmental and economic aspects and determine the external effects caused by the consequences of the consumption of autonomous batteries. Correlation-regression analysis showed that there is a link between indicators of domestic market filling of household batteries and the dynamics of mortality related to cancer. The study provides simplified calculations of external effects that arise in Ukraine because of the consumption of household batteries due to the absence of a system for their collection and disposal. The sum of the total external effects is determined, excluding losses due to air pollution, water pollution, and agricultural losses.

KEYWORDS: externalities, used batteries, correlation-regression analysis

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Introduction

The modern stage of development of economy-based consumption is characterized by an acute complication of the interaction between the environment and humankind and is defined as a technogenic type of economic development, for which significant externalities (external effects) are typical. All people living in the same world and using the same resources are the reason for the external effects to existing. Each person can pursue their goals, and their actions may have a spin-off that affects the condition of others.

Today, the problem of increasing negative environmental externalities related to waste management, especially electronic waste, which also includes used household batteries (batteries and accumulators), is becoming increasingly acute (Grace, 2018; Chaudhary, 2019; Bigum, 2017).

The European Union has a long-established practice of handling used household batteries. According to the Statistics Committee of the European Union, during 2012-2018, the total number of household power supplies sold was relatively constant, and the dynamics of batteries collected from the population shows a clear upward trend (Eurostat, 2020). In 2012, 173 thousand tons of batteries and accumulators were sold in the EU countries, and 64 thousand of them were sent to specialized collection points, that is, 37% of their total number, and in 2018 this percentage increased to 46% (88 thousand tons were collected out of 191 thousand tons sold) (Eurostat, 2020).

Poland, Ukraine's neighbor, has achieved particular success in managing battery and accumulator waste. In the period from 2012 to 2018, the number of batteries collected increased by more than 3.5 times (from 2.9 to 10.7 thousand tons, respectively), while the number of batteries sold increased by only a quarter (from 10.6 to 13.3 thousand tons, respectively) (Statistics Poland, 2018).

The issue of handling used batteries is extremely relevant in Ukraine, since the systems for collecting used batteries in our country do not exist, and most of them are on landfills. Over time, harmful substances contained in galvanic elements freely enter the environment and cause irreparable damage not only to the environment but also to public health.

The goal of this work is to study the environmental and economic aspects and determine the external effects caused by the consequences of the consumption of autonomous batteries.

An overview of the literature

Theoretical foundations of the problem of externalities are widely represented in the works of foreign scientists. In fact, P. Samuelson introduced the term «external effect» into scientific parlance in 1958 (Samuelson, 1954). However, A. Pigou carried out the development of basic approaches to the analysis of externalities much earlier (Pigou, 1920). He justified the difference between private and public costs and benefits and proposed government regulation of externalities through taxes and subsidies. In the 1960s, R. Coase worked on the problem of externalities and saw the neutralization of the problem of externalities in a clear distribution of property rights to resources and minimization of transactional costs.

Among modern scientists T. Litman, W. Fransen, J.M.W. Dings, R.C.N. Wit, B.A. Leurs and M.D. Davidson are noteworthy. Their works are devoted to researches of an estimation of external effects of auto- and air transport (Litman, 2009; Dings et al., 2003). Externalities of waste, including electronics, were studied by Sindhuja M., Narayanan K. and Krishnan T S. (Sindhuja, Narayanan, 2018; Krishnan, 2018). Approaches to study the external effects of spent power sources are found in the works of Tang Y., Zhang Q, Li Y., Li H., Pan X., Mclellan B. And Lamjon L.M. (Tang et al., 2019; Lamjon, 2012).

M. Fairbrother studied the concept of externalities in the social sciences (Fairbrother, 2016), and A. V Houndekon, H. De Groote, and C. Lomer carried out the study of the influence of external effects on public health (Houndekon et al., 2006).

Many publications are devoted to the study of the negative effects of e-waste on public health. In particular, the work of Zeng X., Kuchhal P., Sharma U.C. and Kuntawee, C. is devoted to the study of serious diseases caused by heavy metals contained in electronic waste, including spent batteries (Zeng et al., 2017; Kuntawee et al., 2020; Kuchhal, Sharma, 2019).

Ukrainian authors, who work on this topic, studied the mechanisms of distribution of public goods and the features of using government tools to avoid externalities (Krasnikova, 2009), the development of theoretical and methodological principles for assessing the economic consequences of negative external effects of environmental pollution in the field of environmentally caused diseases of the population (Kurbatko, 2017).

In addition, among the studies available, a number of important issues relating to the problem of handling used batteries that need to be addressed immediately have been neglected. In particular, it is the development of institutional support for controlling the electronic waste management system and improving the system of their statistical reporting, which will help to harmonize the legislation of Ukraine and the EU in the field of state regulation of used batteries.

Research methods

Fundamental and modern provisions of environmental economics, economic and ecological theory of environmental management, and waste management became the basis of the theoretical and methodological foundations of this study.

In accordance with the goal, the following research methods were used: methods of logical generalization and scientific abstraction (when clarifying the conceptual framework of the study); market research methods (when identifying patterns of formation and development of the market for household batteries); comparative method (when studying trends in the field of electronic waste management); the method of correlation-regression analysis (when studying and evaluating the investigative relationships between the indicators of domestic market filling of household batteries and dynamics of mortality related to cancer).

Results of the research

Economists characterizing externalities distinguish several types, classes of these phenomena. Thus, both negative and positive external effects of production and consumption are distinguished by the criterion of the "source of occurrence". The author classifies the problem of handling used batteries as externalities of goods consumption. There are several definitions of external effects in the modern economical literature. The author proposes the following definition:

Externalities of consumption are public losses that are incurred by stakeholders of the socio-economic and ecological system because of the consumption of goods whose value does not consider these losses. External effects in the field of handling used batteries are shown in the graph (figure 1).

If used batteries go to landfills, this leads to negative externalities for the population (people incur losses associated with the treatment of water, soil, and air from harmful substances in the batteries, which are not included in their cost). The marginal social costs from used batteries landfill placement are marked by the MSC, and the marginal private costs from used batteries landfill placement are marked by the MPC. As batteries have now become an essential necessity with no alternative, the inelastic curve of demand for used batteries recycling is marked as D. Then the cause of external effects is the difference in social and private values.

$$MEC = MSC - MPC. \quad (1)$$

Used batteries pollute the environment with heavy metals, the amount of which depends on the amount of waste generated. The proposal to dispose of waste batteries in landfills without taking into account the negative impact on the population is shown by line S1. If the social costs of battery waste disposal in the landfill had been taken into account (in their price), the amount of batteries thrown into the garbage can would have been at a lower S2 level. Since Q1> Q2, there is overproduction, which is associated with negative external effects. If electronic waste producers are forced to pay for the external effect (move from equilibrium point A to equilibrium point B), prices will increase, and the amount of waste generated in the landfill will decrease.

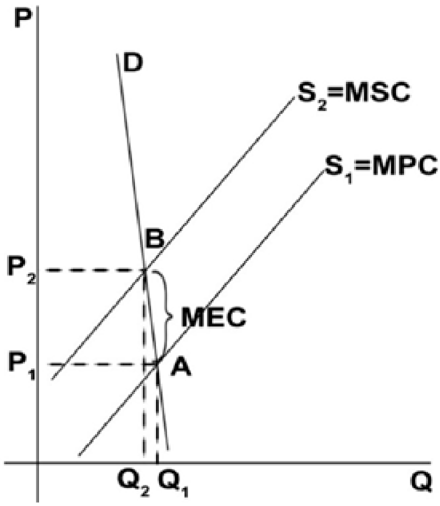

Figure 1. Negative externalities of used batteries
Source: author's work.

In landfills/dumps, used batteries become dangerous immediately after damaging the shell of a battery. Usually, this happens within 6-7 weeks, as the batteries and accumulators are affected by the elevated temperature and acidic (with pH less than 7) filtrate of the polygon. During the whole period of landfill existence, the filtrate serves as a permanent source of groundwater pollution. The disposal of used batteries in solid domestic waste landfills leads to leaching of heavy metals and increase of the concentration of heavy metals in the polygon filtrate (especially – zinc and manganese) (Smirnova, Sakulina, 2016).

Due to the unsatisfactory condition of landfills in Ukraine, landfill fires have become more frequent. For example, the last cases of fire were recorded in September 2019 on the territory of Trypillya village of Kyiv region, Berdychiv city of Zhytomyr region, and Pryluka city of Chernigiv region. The biggest tragedy at the landfill in Ukraine was the fire on May 30, 2016, at the landfill in Hrybovychi village in Lviv region. It partly lasted for two months, covered an area of 800 m^2, and killed four people.

In 5% of cases, used batteries as part of municipal solid waste are sent to incineration plants. It is established that the combustion of alkaline manganese zinc batteries causes the increase of metal concentration in slag and fly ash of incinerators. If gas treatment plants are not efficient enough, some heavy metals will also be present in the combustion gases. When one AA size nickel-cadmium accumulator, weighing about 20 g, is incinerated together with MSW, 3 g of cadmium in the form of steam and fly ash is released into gases, the treatment plants trap part of this amount, the rest is emitted to the atmosphere (12%, which is 0.36 g). The penetration of one manganese zinc battery into the incinerated MSW leads to the emission of up to 4 g of zinc into the gases, while the emission into the atmosphere is 4%, which is 0.045 g (Smirnova, Sakulina, 2016). Table 1 shows the structure of external effects in the field of handling used batteries.

Table 1. Main external effects in used batteries management

	External effect (MECi)	Description
1	Land contamination	Damage caused by contamination of land resources with toxic substances from used batteries due to lack of a system for their collection and disposal.
2	Air pollution	Damage from air pollution caused by used batteries combustion, which gets into waste incineration plants as part of MSW.
3	Contamination of water bodies	Damage from contamination of groundwater, rivers, and reservoirs with heavy metals that seep through the soil as a result of the disposal of used batteries in landfills.
4	Damage to agriculture	Losses of crop and livestock production associated with a reduced quality of soil and water because of the heavy metals that are part of the used batteries.
5	Harm to public health	Damage to public health caused by contaminated drinking water, air, and environmentally hazardous foodstuffs, which is the result of heavy metals from used food sources entering the environment. This leads to increased morbidity in the population, deteriorating working and rest conditions, and reduced life expectancy.

Source: author's work.

Thus, we can record the total social costs for the production of household food sources, taking into account externalities in the following form:

where MECi – external costs of the i-th kind (i = 1, ..., 5, see table 1).

The calculation of external effects faces serious objective and subjective difficulties. For example, human health is the result of a number of social, hygienic, environmental, and economic factors. It is difficult to characterize the role of each of them, but they cannot be ignored. Although the problem has not been sufficiently researched and there are no clear evidences of the population's disease caused by heavy metals contained in used batteries, it is impossible to ignore their harmful effect on the health of Ukrainians.

Table 2 contains a list of poisonous substances in batteries and their impact on human health.

Table 2. The impact of hazardous substances from used batteries on human health

Element	In which batteries can be founded	Health impact
Zink (Zn)	manganese zinc and alkaline batteries	Zinc has a generally toxic, irritating effect: causes nausea, cough, skin irritation, mucous membranes, and insomnia. Carcinogen.
Manganese (Mn)	manganese zinc and alkaline batteries	In the human body, excess manganese leads to neurological diseases, causes myocardial dystrophy and vegetative vascular dystonia. It affects cholesterol metabolism and atherosclerosis progression.
Cadmium (Cd)	nickel cadmium batteries	Excess cadmium in the body leads to impaired kidney function, increased blood pressure, reduced number of red blood cells. Cadmium causes reproductive disorders. It accumulates in the body. Carcinogen.
Mercury (Hg)	mercury zinc elements	Mercury has a bad effect on the kidneys, digestive organs, central nervous system, and heart, sharply reduces blood pressure, and has an extremely negative effect on human reproduction, as well as on the fetus. It accumulates in the body.
Nikel (Ni)	nickel cadmium and nickel-metal hydride batteries	Irritates deep airways, causing pneumonia and pulmonary edema, regardless of the path of entry into the body. A significant general toxic effect is also directed at the nervous system. Carcinogen.

Source: Smirnova, Sakulina, 2016.

Table 2 shows that most of the poisonous substances in batteries are carcinogens, i.e., substances that cause malignancies.

Correlation-regression analysis showed that there is a link between indicators of domestic market filling of household batteries and the dynamics of mortality related to cancer.

The data for Ukraine from 1993-2013 were used for the analysis. Starting from 2014, there are no statistical data on three oblasts (Donetsk Oblast, Lugansk Oblast, AR of Crimea).

Figure 2 shows the dynamics of mortality related to cancer of the Ukrainian population. In 1993, this figure was 332 thousand people, and by 2013, it has grown to 440 thousand people (by 32.5%) and has a clear tendency to increase.

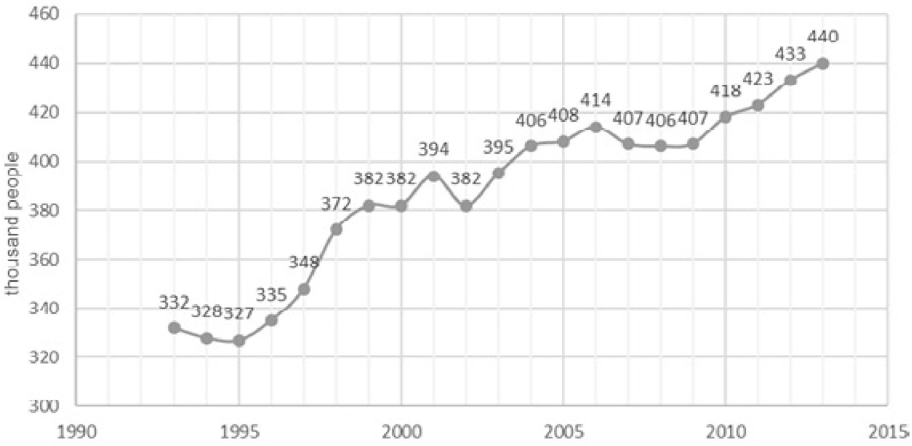

Figure 2. Statistics of cancer diseases of the population of Ukraine

Source: author's work.

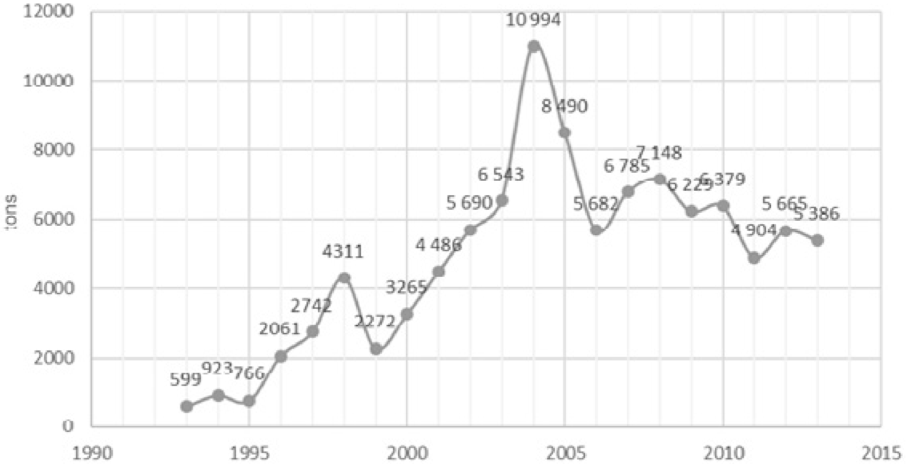

Figure 3. Battery imports in Ukraine in 1993-2013

Source: author's work.

There is also a growing number of batteries imported to Ukraine, providing the performance of portable equipment used in a variety of spheres of human activity. According to the State Fiscal Service of Ukraine, 101 320 tons of batteries were imported to our country in the period from 1993 to 2013 (figure 3).

Table 3 shows the intermediate values for calculating the correlation coefficient and correlation relation equation coefficients, where Y is the number of cancer patients; X is the number of imported batteries.

Table 3. Calculation table of intermediate values

	Year	Number of cancer patients, thousands (Y)	Y2	Number of imported batteries, tons (X)	X2	XY
1	1993	332	110224	599	358801	198868
2	1994	328	107584	923	851929	302744
3	1995	327	106929	766	586756	250482
4	1996	335	112225	2061	4247721	690435
5	1997	348	121104	2742	7518564	954216
6	1998	372	138384	4311	18584721	1603692
7	1999	382	145924	2272	5161984	867904
8	2000	382	145924	3265	10660225	1247230
9	2001	394	155236	4 486	20124196	1767484
10	2002	382	145924	5 690	32376100	2173580
11	2003	395	156025	6 543	42810849	2584485
12	2004	406	164836	10 994	120868036	4463564
13	2005	408	166464	8 490	72080100	3463920
14	2006	414	171396	5 682	32285124	2352348
15	2007	407	165649	6 785	46036225	2761495
16	2008	406	164836	7 148	51093904	2902088
17	2009	407	165649	6 229	38800441	2535203
18	2010	418	174724	6 379	40691641	2666422
19	2011	423	178929	4 904	24049216	2074392
20	2012	433	187489	5 665	32092225	2452945
21	2013	440	193600	5 386	29008996	2369840
	Σ	8139	3179055	101320	630287754	40683337

Source: author's work.

The correlation coefficient is determined by the formula:

$$r_{(X,Y)} = \frac{\sum_{i=1}^{n} X_i * Y_i - \frac{1}{n}\sum_{i=1}^{n} X_i * \sum_{i=1}^{n} Y_i}{\sqrt{\left[\sum_{i=1}^{n} X_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} X_i\right)^2\right] * \left[\sum_{i=1}^{n} Y_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} Y_i\right)^2\right]}} =$$

$$= \frac{4068337 - \frac{1}{21}101320 * 8139}{\sqrt{\left[630287754 - \frac{1}{21}(101320)^2\right] * \left[3179055 - \frac{1}{21}(8139)^2\right]}} = 0.76.$$

The obtained correlation coefficient shows that the correlation between the variables X and Y is straight, and the Chaddock scale connection force is high.

The Student's criterion was used to evaluate the significance of the correlation coefficient:

$$t_{(r)} = \frac{r_{(X,Y)}}{\sqrt{1 - (r_{(X,Y)})^2}} * \sqrt{n-2} = \frac{0.76}{\sqrt{1 - 0.76^2}} * \sqrt{21-2} = 5.097.$$

The table value of the Student's criterion for equal importance α=0.05 and the number of freedom steps ʄ=n-2=21-2=19, t_{table} = 2,093.

Since t_{table}=2,093< t_r = 5.097, being less than 95% suggests that the studied indicators of the number of cancer patients and the number of batteries correlate, so the relationship between them has been proved.

To describe the paired linear regression equation, its coefficients were determined using the least-squares method:

$$b_0 = \frac{\sum_{i=1}^{n} x_i^2 \sum_{i=1}^{n} y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} x_i y_i}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} =$$

$$= \frac{630287754 * 8139 - 101320 * 40683337}{21 * 630287754 - 101320^2} = 339.32$$

$$b_1 = \frac{n\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2} = \frac{21 * 40683337 - 101320 * 8139}{21 * 630287754 - 101320^2} = 0.01.$$

The paired linear regression equations have the following form:

$$y=339.32+0.01x$$

Analyzing the calculations, we can conclude that with the increase in the number of batteries in the Ukrainian market by 1 ton the number of cancer patients increases by 0.01 thousand people.

To analyze the overall quality of the regression model, we use the coefficient of determination R^2.

For our model, $R^2=0.58$ (58% of the variation in y can be explained by the x-variables). For reliable models, it is assumed that the coefficient of determination should be at least 0.5; therefore, we consider our model is acceptable.

Let us estimate the quality of the regression equation using the absolute approximation error. The average approximation error is the average deviation of the calculated values from the actual ones:

$$\overline{A} = \frac{\sum |y_i - y_x| : y_i}{n} * 100\%$$

$$\overline{A} = \frac{1.01}{21} * 100\% = 4.8\%$$

Since the error is less than 12%, this equation can be used as a regression.

Let us evaluate the statistical reliability of modelling using F-test. To do this, we will test the null hypothesis (H_0) about the statistical insignificance of the obtained regression equation according to the condition: if $F_{fact} > F_{table}$, then H_0 is rejected and the statistical significance, reliability of the regression equation is recognized.

To calculate the F_{fact}, we use the formula:

$$F_{fact} = \frac{R^2}{1 - R^2}(n - 2) = \frac{0.58}{0.42} * 19 = 26.23$$

The F_{table} (at a significance level of $\alpha = 0.05$) is 4.38.

Since $26.23 > 4.38$, the null hypothesis H_0 is rejected, i.e., according to Fisher's test, the regression is adequate.

Conclusions

The study provides simplified calculations of external effects that arise in Ukraine because of the consumption of household batteries due to the absence of a system for their collection and disposal. Due to the imperfection of the existing statistical reporting system, these calculations were made only until 2013, because since 2014, due to the armed conflict in the East of Ukraine, there are no statistics for three regions – the Donetsk region, the Luhansk region, and the Crimea.

Based on the proposed structure of external effects in the sphere of treatment of used batteries and the correlation regression analysis, it is proposed to take into account expenditures on public health protection when determining the value of external effects.

Thus, according to the Law of Ukraine “On Approval of the National Cancer Control Program for the period until 2016” the amount of funding for the implementation of the program for 2013 amounted to 472 243.6 UAH. According to the correlation regression analysis, the increase in the number of domestic batteries by one ton leads to an increase in cancer patients by 10 people. Therefore, we concluded that the total number of cancer patients, whose disease could be caused by external effects of handling used batteries, (5386 tons were imported in 2013), is 53 860 people.

Therefore, we believe that 57 807 UAH of the total amount of state budget expenditures for the funding of the National Cancer Program, which amounts to 472 243.6 UAH in 2013, are funds for treatment of cancer patients, whose disease could be caused by external effects of handling used batteries. Adding to this amount the ecological and economic damage from the pollution of land resources by used batteries, which is 400 360 000 UAH (Shuptar, 2013), the amount of total external effects of used batteries is 458 167 UAH (excluding losses due to air pollution, water pollution, and agricultural losses).

The practical significance of the results obtained in this study can be applied in the formation of the Ukrainian system of the electronic waste management system, improvement of the methodology of state statistical monitoring of household battery waste generation, and the development of unified environmental standards for the development of cross-border cooperation between Ukraine and neighbouring states in the field of sustainable and environmentally sound development.

Taking into account the determined amount of general external effects will contribute to the effective use of economic instruments in the implementation of environmental policy, reduce public spending on health protection, and reduce economic losses from damage caused by the uncontrolled release of used batteries into the environment.

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The contribution of the authors

Natalia Yosipivna Shuptar-Poryvaieva – 25% (concept and objectives, research, interpretation of data).

Elena Rostislavovna Gubanova – 25% (concept and objectives, literature review, research).

Natalia Mykolaivna Andryeyeva – 25% (concept and objectives, analysis and interpretation of data).

Tetiana Ivanivna Shevchenko – 25% (concept and objectives, literature review, acquisition of data).

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