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FUZZY MODEL OF SUSTAINABLE DEVELOPMENT WITH THE INCLUSION OF FINANCIAL VARIABLES

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Abstract. The aim of the article was to build a model based on fuzzy logic describing the level of sustainable development for the individual EU Member States in 2009–2019 and to conduct fuzzy simulations as a result of which scenarios for the prediction of sustainable development acknowledging financial variables (the share of environmental taxes, a deficit, a debt). The original research approach is expressed by including fuzzy models in the analysis of the level of sustainable development with the inclusion of financial variables. The Netherlands achieved the highest value (the highest level of sustainable development) (0.571). Slovenia (0.564) and Denmark (0.559) came second and third. The lowest average value (the lowest level of sustainable development) was recorded for Slovakia (0.423). After 10 years there are evident changes in the distribution of individual typological groups. In 2019, the countries belonging to the first and second typological groups were located primarily in the northern and central Europe. The scenario analysis showed that in the case of most countries, if the analyzed variables remained at the maximum or minimum level throughout the analyzed period, it would not significantly affect the assessment of their level of sustainable development, their ranking positions, and inclusion into typological groups.

Keywords: fuzzy model, sustainable development, scenario, public policies, tax, expenditures, debt.

JEL Classification: G18, H23, O15, O30, O44, Q01.

Introduction

Sustainable development is well recognized and described in the literature on the subject (Mensah, 2019). It is an interdisciplinary issue that can be viewed from the point of view of various disciplines. There is also a wealth of achievements regarding rankings and indexes that try to measure the level of sustainable development and the dynamics of its changes.

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However, there is a research gap regarding public policies and the role of the state in creating conditions for sustainable development (Morita et al., 2020). The roles of the state's expenditure policy, debt policy, and environmental taxes are important in this respect. The article fills this gap in research and includes qualitative variables in analyzing the level of sustainable development in individual European Union countries. The original approach presented in the article consists in using a fuzzy logic model utilized to create simulations leading to the elaboration of sustainable development scenarios (optimistic and pessimistic). The article poses the following research questions:

1. Can the existing budget constraints (soft and hard) impact the level of sustainable development?
2. What role does the expenditure and tax policy support sustainable development?
3. How should the (public) finances model for sustainable development be shaped in the context of sustainable development scenarios?

The paper is organized as follows: in Section 1 the theoretical aspects of finance and sustainable development are presented. Section 2 discusses the methodological approach, data collection procedure, and the description of the methods. Section 3 discusses the research results, and the last Section contains the conclusion.

1. Literature review

Due to the popularization of sustainable development, it has become the subject of many studies. The analysis of the literature allowed the authors to identify the most common research directions in this field:

– relationship between Sustainable Development Goals and finance (Sachs et al., 2019; Zioło et al., 2021; Khan, 2019);
– Sustainable Development Goals and their impact on development (Gupta & Vegelin, 2016) and enterprises (Mio et al., 2020; Garcia-Sanchez et al., 2020), investors (Khan, 2019; Liang & Rennenboog, 2020);
– relationship between sustainable development and economy (Gambetta et al., 2019), including the circular economy (Geissdoerfer et al., 2017; Andersen, 2007) and green economy (Aldieri & Vinci, 2018; Levidow, 2018; Ali et al., 2021);
– relationship between sustainable development and finance in the broad sense (Ryszawska, 2016; Wang & Chen, et al., 2021; Schoenmaker, 2018; Schmidt-Traub & Sachs, 2015);
– Sustainable Development Goals and risk ESG (Mezzanotte, 2020; Sciarelli et al., 2020; Folqué et al., 2021; Lokuwaduge & Heenetigala, 2017).

Sustainable development is based on mutual and intergenerational responsibility and solidarity and three pillars (environmental, social, and economic). The decision-makers must consider the complementarity and relationship (compromises) between these pillars (Mensah, 2019).

Worldwide, the implementation of the SDGs is still at an early stage (Barua, 2020). The challenge is to maintain the right relationship between achieving short-term and long-term goals (matching the concept of sustainable development). The decision to implement the SDGs affects the allocation of resources, and therefore must also be included in budgets (Young, 2017). Vaillé and Brimont (2016) pointed out that a budget needs to acknowledge the sustainable development goals, and reserving funds for the implementation of the adopted goals and tasks conforming to the SDGs should also prevent conflicts between them. Hege et al. (2019) highlighted the benefits of integrating the SDGs into the budgeting process. Including SDGs in the budget can help to improve the coherence of implemented policies. This coherence should be understood both in the context of the implemented tasks and the resulting allocation of resources (e.g., the compliance of implemented infrastructure projects with environmental objectives (climate)) and including obligations resulting from concluded international agreements in the budget (e.g., from the 2030 Agenda). Incorporating the sustainable development goals into the policies introduced within the country will ensure the compliance of implemented projects with the SDGs (United Nations Development Programme [UNDP], 2020). The United Nations supports countries in creating an Integrated National Financing Framework (INFF) aimed at strengthening financing for entities (both from the public and private sectors) pursuing the goals of sustainable development (UNDP, 2020).

Ensuring financing for the implementation of the SDGs is extremely important both at the national and international levels. Barua (2020) points to a financing gap in this field, especially in developing countries. Gambetta et al. (2019) show on the example of Uruguay that in countries where the financial market is not developed, funds for achieving the goals come from the state budget. Sergi et al. (2019) point out that public-private partnership is a prospective mechanism for financing sustainable development, as it allows for the consideration of interests of both private and public entities, the unification of investments made by the private and public sectors, and increasing the effectiveness of the implementation of initiatives in line with the SDG concept.

Decision-makers have various tools to encourage various groups of entities (enterprises, households) to take actions consistent with the concept of sustainable development (Lyytimäki, 2014). Among them, a special place is occupied by economic instruments related to environmental policy objectives. Their importance was emphasized in the Rio Declaration and Agenda 21 (Panaiotov, 1994).

Sterner and Köhlin (2017) drew attention to the importance of environmental taxes in implementing environmental policy. Majic et al. (2021) verified that the main reason for introducing environmental taxes is the so-called double benefit hypothesis stating that green taxes have a positive effect on the environment and economic growth by replacing more harmful taxes. They pointed out that, on the one hand, they are the most effective instrument for correcting market inefficiency in solving environmental problems. However, on the other hand, they may have an uneven impact on individual social groups, creating new groups of the so-called losers (i.e., poorer entities), which are vehemently opposed to the introduction of new ecological taxes. Esen et al. (2021), based on an analysis of environmental tax revenues in the EU-15, noted that well-designed environmental taxes (set at an optimal level) can reduce environmental problems/ecological imbalances but should not be combined with fiscal instruments such as tax exemptions, refunds or tax breaks. Cai et al. (2018) attempted to determine the level of pollution tax of industrial waste.

Environmental taxes are one of the most important fiscal policy instruments to internalize "negative externalities" (Toprak, 2018). Shahzad (2020), based on the conducted research, showed that the environmental tax influences (changes) the investment and consumption behaviour of entrepreneurs (manufacturers), motivating them to introduce more profitable and environmentally friendly production methods (Yuan & Zhang, 2020). These results are in line with the results of the studies by Andersson (2019) and Criqui et al. (2019).

Environmental taxes also influence consumer behaviour. Raising the prices of environmentally harmful goods in relation to other goods stimulates consumers to take actions consistent with the concept of sustainable development (Majic et al., 2021). The strength of the impact of environmental taxes on the behaviour of companies and consumers depends on many factors. Li et al. (2021) showed that the larger the entity, the smaller the impact of environmental taxes on its behaviour. The research conducted by Shmelev and Speck (2018) on the example of Sweden, which carried out the "green fiscal reform" and was the first to implement the CO2 tax, showed that the effectiveness of environmental taxes on the behaviour of entities depends on the interconnection between taxes and the structure of the state's fiscal system.

Individual taxes play different roles in implementing sustainable development, including environmental policy. Sterner and Köhlin (2017) pointed out that most European countries have relatively high levels of environmental taxes. Mokrisova (2018) showed that in the case of the Slovak Republic, the highest revenues from environmental taxes come from energy taxes, although their amount is the second-lowest among European countries. Binswanger (2001), proving the legitimacy of introducing energy taxes, drew attention to the fact that the "side effect" of using time-saving technologies is increased energy consumption. With the introduction of energy taxes, manufacturers would optimize their energy consumption when deciding on the production technology.

The relationship between the expenditure of the public finance sector and the concept of sustainable development is becoming more and more visible (Fausto, 2010). Garba and Abdullahi (2013) pointed to a positive and long-term relationship between public spending and economic growth. Zhuravlov et al. (2021), based on the experience of Hungary, Poland, Bulgaria, and Latvia, showed that appropriate debt management affects the sustainable development of entrepreneurship and the entire country. Citizens increasingly aware of the importance of the impact of human activities on the environment accept the growing public spending on environmental protection, including the implementation of modern, pro-ecological technologies. The positive impact of investments on economic growth was confirmed in Tung's research (2022).

The country's level of innovation and its economic entities is determined by the amount of expenditure on research and development (R&D). Adedoyin et al. (2020) showed that research and development expenditure significantly contribute to countries' environmental sustainability. They also confirmed feedback between the ecological footprint, research and development expenditure, and renewable and non-renewable energy sources. Artha et al. (2021) confirmed that R&D spending significantly impacted Austria's CO_2 emissions in the period 1996–2006. They pointed out that the impact of research and development on CO_2 emissions can be either positive or negative (Wang &d Chen, 2021). Therefore the role of the state is to support those programs that reduce CO_2 emissions (Petrović & Lobanov, 2020). The subject of research by Koçak et al. (2021) was the environmental efficiency of R&D spending in terms of energy efficiency, renewable energy, water, and fuel cells, fossil energy, nuclear energy, and other energy and storage technologies in OECD countries. The results indicate that only in the US, spending on energy research and development ensures the country's environmental performance. In Japan, Germany, France, Canada, and Italy, this type of spending does not ensure environmental efficiency. Portugal, Hungary, and Slovakia have the lowest environmental efficiency spending on energy research and development.

Among the goals of sustainable development is the reduction of inequality. One of the indicators used to measure social inequality is the Gini coefficient. Research by Holden et al. (2014) shows that sustainable development requires a Gini coefficient of less than 40 and the use of renewable energy at 27%. Bono et al. (2016) used the Gini index to investigate the disparities in sustainable development across Italian regions. For this purpose, the Gini index was generalized considering energy and the environment. The results confirm the positive impact of some EU policies on reducing inequality between Italian regions. Asongu and Odhiambo (2020) investigated how increasing gender inclusion affects inequalities in the context of recommendations for policies for sustainable development. They showed that increasing the rate of dynamics of gender inclusion has a net positive effect on reducing inequality.

Reducing gender inequalities is part of the social aspect of sustainable development (Murphy, 2012). Raising the social status of employees and ensuring safe and decent working conditions are activities in line with CSR concepts. Glonti et al. (2020) showed that the introduction of CSR activities by the company causes the company to implement the principles of sustainable development, taking into account the requirements of social, economic, and environmental harmonization. Research by Dhakal and Burges (2020) showed that the implementation of the social aspect of sustainable development in ensuring decent working conditions for employees is determined by the level of development of the country. In countries where most employees are in the informal sector (e.g., Nepal), the effectiveness of social policy in this area implemented at the national level is limited.

2. Research material and method

The research covered 28 European Union member states. In order to assess their level of sustainable development, 12 variables were used from the Eurostat and World Bank databases from 2009–2019, some of which were indexed. They included:

X_1 – shares of environmental in total tax revenues, % of total taxes, Total environmental taxes;

X_2 – expenditure on social protection (% of GDP);

X_3 – sustainable Development Index (SDI);

X_4 – Green Growth Index;

X_5 – European Social Progress Index;

X_6 – research and development expenditure (% of GDP);

X_7 – general government deficit/surplus (% of GDP);

X_8 – general government gross debt (% of GDP);
X_9 – Gini coefficient of equivalised disposable income before social transfers (pensions included in social transfers);
X_{10} – Gini coefficient of equivalised disposable income before social transfers (pensions excluded from social transfers);
X_{11} – International Tax Competitiveness Index;
X_{12} – Human Development Index (HDI).

The variables presented above were classified into one of three groups:
group 1 – includes variables measuring the state of the environment and the impact of human activities on it (X_3, X_1);
group 2 – includes variables related to social development (X_2, X_5, X_6, X_{12});
group 3 – includes variables related to the economic situation and the state of inequality in terms of income of societies (X_4, X_7, X_8, X_9, X_{10}, X_{11}).

Among the variables, stimulants dominate, i.e., features positively influencing the studied phenomenon; only three are destimulants (X8, X9, X10), so an increase in their level will negatively impact the analysed phenomenon. Fuzzy models were used to construct synthetic measures characterizing the level of sustainable development in the EU countries in the years 2010–2019. The basic definitions related to the construction of these models are presented below.

A fuzzy set in mathematics is defined by the membership function (Ross, 2010):

$$\chi_A : X \to \{0,1\}. \tag{1}$$

This notation means that each element x∈X belonging to set A is assigned 1, and when the element x does not belong to set A – 0. In the case of fuzzy sets, the affiliation of elements x to set A is described by the membership function (Chen & Pham, 2001):

$$\mu_A : X \to [0,1]. \tag{2}$$

In that case: $\mu_A(x) = 1$ denotes full membership; $0 < \mu_A(x) < 1$ denotes partial membership; $\mu_A(x) = 0$ denotes lack of membership.

In the description of systems using fuzzy logic, linguistic variables are used (Klir & Yuan, 1995; Walaszek-Babiszewska & Bryniarska, 2018; Zadeh, 1965):

$$\langle x_{name}; L(X), X, G, M \rangle, \tag{3}$$

where: x_{name} – the name of the linguistic variable; $L(X)$ – a set of values that a linguistic variable takes; X – space for reflection; G – semantics/grammar, generating linguistic values LX_i; M – semantics ascribing to each linguistic value LX_i a fuzzy set that is appropriate in terms of meaning $M(LX_i)$, as a subset of space X.

The fuzzy model is described by the so-called knowledge base (rules) that allows determining the impact of the levels of linguistic variables and their interrelationships on the described system. A single rule can take the form (Shepherd & Shi, 1998):

$$\text{IF } x \text{ is } A \text{ THEN } y \text{ is } C, \tag{4}$$

where A and C are fuzzy variables described by certain membership functions. The elements X and Y are related by the membership function levels, respectively: $\mu_A(x)$ and $\mu_C(y)$.

By defuzzification, one means an operation converting the system output signals (the result of applying fuzzy algorithms) from the qualitative domain (fuzzy value) to the quantitative (numerical) domain. The most frequently used sharpening methods include the centre of gravity method (Kacprzyk, 2001):

$$a = \frac{\sum_{i=1}^{n} x_i \mu(x_i)}{\sum_{i=1}^{n} \mu(x_i)}. \tag{5}$$

The research, the results of which are presented in this paper, consisted of the following stages:

a. The unification of the intervals of the variability of individual variables using the zeroed unitarization method, the formal notation of which is given by the formula (Kukuła & Bogocz, 2014; Kiselakova et al., 2020):
   - for stimulants:

$$z_{ij} = \frac{x_{ij} - \min_j(x_{ij})}{\max_j(x_{ij}) - \min_j(x_{ij})}, \tag{6}$$

   - for destimulants:

$$z_{ij} = \frac{\max_j(x_{ij}) - x_{ij}}{\max_j(x_{ij}) - \min_j(x_{ij})}. \tag{7}$$

b. The construction of indicators enabling the classification of EU Member States according to three groups of variables (measuring the state of the environment, social development, and economic situation) for each of the periods of the analysis:

$$I_{g_{ti}} = \frac{\sum_{j=1}^{k_t} z_{tij}}{k_t}, \tag{8}$$

   where: I_{g_i} – the value of the index for the g-th group in the t-th year and the i-th country ($g = 1$ – "environment"; $g = 2$ – "society"; $g = 3$ – "economy"); k_t – the number of variables (factors) in the g-th and t-th year; z_{tij} – normalized values of variables (factors) in a t-th year.

c. Building a model based on fuzzy logic, describing the level of sustainable development for the individual EU Member States for each analysed period based on the indicators calculated in point 2. Table 1 defines the values of linguistic variables and the base of rules, constituting the essential elements necessary for constructing a fuzzy model.

Table 1. Linguistic input variables

Linguistic variable	Properties	Level	Index value
fl_x1 – "environment"	stimulant	low	$\bar{I}_{1t} - S(I_{1t})$
		mid	$\bar{I}_{1t}$
		high	$\bar{I}_{1t} + S(I_{1t})$
fl_x2 – "society"	stimulant	low	$\bar{I}_{2t} - S(I_{2t})$
		mid	$\bar{I}_{2t}$
		high	$\bar{I}_{2t} + S(I_{2t})$
fl_x3 – "economy"	stimulant	low	$\bar{I}_{3t} - S(I_{3t})$
		mid	$\bar{I}_{3t}$
		high	$\bar{I}_{3t} + S(I_{3t})$
U – sustainable development	stimulant	low	0.25
		mid	0.50
		high	0.75

– The base of rules:

IF (fl_x1 is low **OR** fl_x1 is mid **OR** fl_x1 is high) **AND** fl_x2 is low **AND** fl_x3 is low **THEN** U is low
IF fl_x1 is low **AND** (fl_x2 is low **OR** fl_x2 is mid **OR** fl_x2 is high) **AND** fl_x3 is low **THEN** U is low
IF fl_x1 is low **AND** fl_x2 is low **AND** (fl_x3 is low **OR** fl_x3 is mid **OR** fl_x3 is high) **THEN** U is low
IF (fl_x1 is low **OR** fl_x1 is mid **OR** fl_x1 is high) **AND** fl_x2 is mid **AND** fl_x3 is mid **THEN** U is mid
IF fl_x1 is mid **AND** (fl_x2 is low **OR** fl_x2 is mid **OR** fl_x2 is high) **AND** fl_x3 is mid **THEN** U is mid
IF fl_x1 is mid **AND** fl_x2 is mid **AND** (fl_x3 is low **OR** fl_x3 is mid **OR** fl_x3 is high) **THEN** U is mid
IF fl_x1 is low **AND** fl_x2 is mid **AND** fl_x3 is high **THEN** U is mid
IF fl_x1 is mid **AND** fl_x2 is low **AND** fl_x3 is high **THEN** U is mid
IF fl_x1 is mid **AND** fl_x2 is high **AND** fl_x3 is low **THEN** U is mid
IF fl_x1 is low **AND** fl_x2 is high **AND** fl_x3 is mid **THEN** U is mid
IF fl_x1 is high **AND** fl_x2 is mid **AND** fl_x3 is low **THEN** U is mid
IF fl_x1 is high **AND** fl_x2 is low **AND** fl_x3 is mid **THEN** U is mid
IF (fl_x1 is low **OR** fl_x1 is mid **OR** fl_x1 is high) **AND** fl_x2 is high **AND** fl_x3 is high **THEN** U is high
IF fl_x1 is high **AND** (fl_x2 is low **OR** fl_x2 is mid **OR** fl_x2 is high) **AND** fl_x3 is high **THEN** U is high
IF fl_x1 is high **AND** fl_x2 is high **AND** (fl_x3 is low **OR** fl_x3 is mid **OR** fl_x3 is high) **THEN** U is high

The *sets* package included in the *R* environment was used for the calculations (Meyer et al., 2017).

d. Determining the level of sustainable development for individual countries and periods by defuzzification of the values of fuzzy variables obtained from the model built in point 3. The obtained values were in the range [0,1], where 1 means a high level of development, and 0 – a low level. For ease of reference, these values will be referred to as the synthetic measure in the following section of the paper.

The method of constructing a synthetic measure based on fuzzy logic has indisputable advantages. Compared to the classical taxonomic techniques of constructing anti-pattern development measures, it eliminates the problem of selecting an aggregation measure. It is important because the most frequently used arithmetic mean is not resistant to extreme values of diagnostic variables. At the same time, due to the existence of a specific model of dependence between the variables, it enables simulating the intensity of the analysed phenomenon depending on the levels of the input variables (factors). In turn, the use of classical regression models requires:

- the occurrence of a specific quantitative variable describing the studied phenomenon (a dependent variable);
- considering the non-linear nature of the relationship between the dependent variable and independent variables, the strength and direction of which may change over time;
- the estimation of model parameters for each of the analysed periods.

In the case of models based on fuzzy logic, the rule base enables a simple description of the relationship between the variables and the level of the studied phenomenon without specifying their mathematical nature. At the same time, the described phenomenon does not have to be quantified, and its quantitative description occurs through the process of defuzzification.

3. Research results

Table 2 presents the values of the synthetic measure for each of the EU countries that define the level of their sustainable development in 2009–2019. Due to the lack of comparable data for the variable X_2, in 2019, this variable was not included.

The analyses show that the average value of the synthetic measure determining the level of sustainable development in 28 EU countries was from 0.494 in 2010 and 2011 to 0.504 in 2014, which should be considered a moderate value based on a selected set of variables. At the same time, the disproportion between the countries with the highest and the lowest levels of the analysed phenomenon decreased slightly, which was reflected in the reduction of the range from 0.207 (2009) to 0.160 (2019).

The highest levels of the synthetic measure in individual years were achieved by: Bulgaria (2009 and 2012), Sweden (2010), Netherlands (2011 and 2013–2014), Austria and Malta (2015), Malta (2016 and 2018), Slovenia (2017), Denmark (2019).

In turn, the lowest values were recorded in 2009–2012 for Slovakia, in 2013 and 2015–2019 for Lithuania, and in 2014 for Spain.

Table 2. The level of sustainable development of EU countries in 2009–2019

no.	Countries	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1	Belgium	0.494	0.433	0.547	0.543	0.519	0.443	0.492	0.455	0.473	0.479	0.449
2	Bulgaria	0.616	0.529	0.580	0.602	0.522	0.475	0.494	0.474	0.463	0.482	0.477
3	Czechia	0.461	0.452	0.463	0.477	0.483	0.503	0.493	0.478	0.483	0.486	0.515
4	Denmark	0.580	0.562	0.547	0.533	0.537	0.567	0.551	0.556	0.569	0.563	0.586
5	Germany	0.538	0.463	0.526	0.508	0.469	0.530	0.553	0.550	0.550	0.530	0.519
6	Estonia	0.438	0.482	0.449	0.446	0.432	0.570	0.445	0.442	0.440	0.441	0.494
7	Ireland	0.440	0.500	0.500	0.504	0.525	0.519	0.512	0.508	0.506	0.473	0.456
8	Greece	0.467	0.473	0.413	0.429	0.500	0.466	0.496	0.465	0.459	0.471	0.461
9	Spain	0.491	0.464	0.511	0.508	0.458	0.409	0.446	0.439	0.435	0.434	0.430
10	France	0.552	0.437	0.573	0.572	0.466	0.486	0.439	0.441	0.443	0.449	0.448
11	Croatia	0.531	0.510	0.447	0.448	0.454	0.456	0.440	0.493	0.524	0.472	0.515
12	Italy	0.515	0.469	0.537	0.536	0.532	0.513	0.509	0.525	0.519	0.539	0.493
13	Cyprus	0.426	0.468	0.423	0.426	0.487	0.422	0.433	0.446	0.490	0.424	0.456
14	Latvia	0.557	0.500	0.549	0.567	0.528	0.500	0.551	0.559	0.548	0.545	0.547
15	Lithuania	0.476	0.450	0.413	0.437	0.413	0.439	0.415	0.415	0.415	0.419	0.426
16	Luxembourg	0.536	0.520	0.508	0.502	0.499	0.523	0.515	0.516	0.519	0.535	0.532
17	Hungary	0.450	0.470	0.448	0.469	0.480	0.514	0.508	0.481	0.456	0.472	0.525
18	Malta	0.458	0.538	0.446	0.422	0.510	0.572	0.575	0.574	0.577	0.577	0.571
19	Netherlands	0.579	0.520	0.587	0.581	0.583	0.575	0.560	0.573	0.575	0.576	0.574
20	Austria	0.422	0.463	0.496	0.508	0.561	0.572	0.575	0.562	0.548	0.571	0.566
21	Poland	0.539	0.510	0.505	0.527	0.522	0.490	0.500	0.493	0.479	0.517	0.472
22	Portugal	0.467	0.468	0.465	0.461	0.463	0.468	0.475	0.472	0.478	0.468	0.470
23	Romania	0.512	0.566	0.448	0.471	0.509	0.515	0.492	0.451	0.452	0.444	0.451
24	Slovenia	0.536	0.563	0.563	0.560	0.563	0.569	0.568	0.567	0.578	0.572	0.566
25	Slovakia	0.409	0.418	0.408	0.413	0.431	0.435	0.428	0.420	0.424	0.439	0.427
26	Finland	0.543	0.562	0.566	0.560	0.569	0.574	0.560	0.545	0.545	0.533	0.526
27	Sweden	0.564	0.589	0.443	0.466	0.525	0.546	0.568	0.566	0.559	0.561	0.539
28	United Kingdom	0.470	0.454	0.458	0.451	0.457	0.462	0.463	0.456	0.455	0.458	0.496
min		0.409	0.418	0.408	0.413	0.413	0.409	0.415	0.415	0.415	0.419	0.426
max		0.616	0.589	0.587	0.602	0.583	0.575	0.575	0.574	0.578	0.577	0.586
mean		0.502	0.494	0.494	0.497	0.500	0.504	0.502	0.497	0.499	0.497	0.499
S(x)		0.054	0.045	0.055	0.054	0.043	0.051	0.049	0.051	0.051	0.051	0.048

Figure 1 shows a comparison of the values of diagnostic variables for Denmark and Lithuania, countries with the highest and the lowest values of the taxonomic measure of development in 2019.

Figure 1 shows that in 2019 Denmark showed noticeably better values for seven out of eight stimulants and all three destimulants. The most significant relative differences were noted for the following variables: X_7 (General government deficit/surplus (% of GDP) and X_6 (Research and development expenditure (% of GDP) was 660% and 191%, respectively. Only in the case of a variable X_{11} (International Tax Competitiveness Index), Lithuania achieved a significantly higher value (33.9%).

The analysis of the average values of synthetic measures calculated for individual EU countries in the entire analysed period shows that the Netherlands achieved the highest value (the highest level of sustainable development) (0.571). Slovenia (0.564) and Denmark (0.559) came second and third. In turn, the lowest average value (the lowest level of sustainable development) was recorded for Slovakia (0.423). The third and second-lowest positions were Cyprus (0.446) and Lithuania (0.429). Figure 2 shows the average values of synthetic measures for the analysed countries, ordered in non-decreasing order, throughout the entire research period.

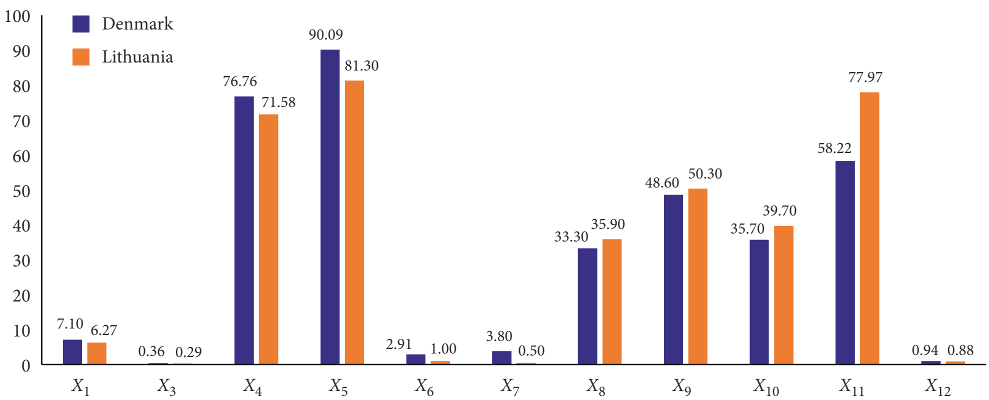

Figure 1. The values of diagnostic variables for Denmark and Lithuania in 2019

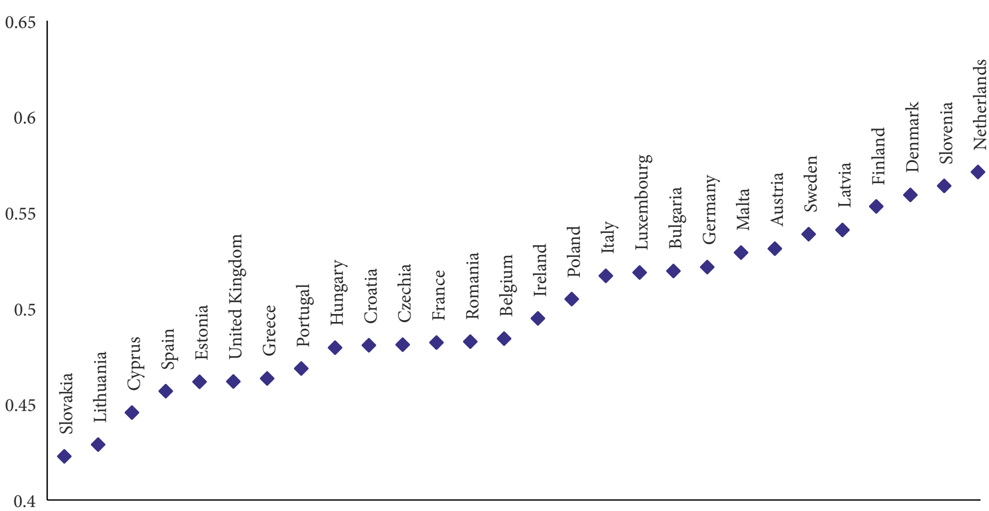

Figure 2. The average values of the synthetic measure by EU countries in 2009–2019

Based on the data presented in Table 1 and using the mean value and standard deviation, the individual countries were classified into one of the four typological groups:

– group 1: $z_{ij} > \overline{z}_j + S_{z_j}$,
– group 2: $\overline{z}_j + S_{z_j} \geq z_{ij} > \overline{z}_j$,
– group 3: $\overline{z}_j \geq z_{ij} > \overline{z}_j - S_{z_j}$,
– group 4: $z_{ij} < \overline{z}_j - S_{z_j}$.

The results are presented in Table 3.

Table 3. EU countries by typological groups in 2009–2019

no.	Countries	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
1	Belgium	3	4	2	2	2	4	3	3	3	3	4
2	Bulgaria	1	2	1	1	2	3	3	3	3	3	3
3	Czechia	3	3	3	3	3	3	3	3	3	3	2
4	Denmark	1	1	2	2	2	1	2	1	1	1	1
5	Germany	2	3	2	2	3	2	1	1	1	2	2
6	Estonia	4	3	3	3	4	1	4	4	4	4	3
7	Ireland	4	2	2	2	2	2	2	2	2	3	3
8	Greece	3	3	4	4	2	3	3	3	3	3	3
9	Spain	3	3	2	2	3	4	4	4	4	4	4
10	France	2	4	1	1	3	3	4	4	4	3	4
11	Croatia	2	2	3	3	4	3	4	3	2	3	2
12	Italy	2	3	2	2	2	2	2	2	2	2	3
13	Cyprus	4	3	4	4	3	4	4	3	3	4	3
14	Latvia	2	2	2	1	2	3	2	1	2	2	2
15	Lithuania	3	3	4	4	4	4	4	4	4	4	4
16	Luxembourg	2	2	2	2	3	2	2	2	2	2	2
17	Hungary	3	3	3	3	3	2	2	3	3	3	2
18	Malta	3	2	3	4	2	1	1	1	1	1	1
19	Netherlands	1	2	1	1	1	1	1	1	1	1	1
20	Austria	4	3	2	2	1	1	1	1	2	1	1
21	Poland	2	2	2	2	2	3	3	3	3	2	3
22	Portugal	3	3	3	3	3	3	3	3	3	3	3
23	Romania	2	1	3	3	2	2	3	3	3	4	4
24	Slovenia	2	1	1	1	1	1	1	1	1	1	1
25	Slovakia	4	4	4	4	4	4	4	4	4	4	4
26	Finland	2	1	1	1	1	1	1	2	2	2	2
27	Sweden	1	1	3	3	2	2	1	1	1	1	2
28	United Kingdom	3	3	3	3	3	3	3	3	3	3	3

The spatial distribution for the first and last years of the analysis is shown in Figures 3 and 4.

The analysis of the data presented in Figure 3 shows that in 2009 there were no significant differences in the level of sustainable development between "old" and "new" EU countries. Regarding the first group of countries, it is observed that the countries of the former EEC and Sweden are characterized by a high level of sustainable development (typological groups 1 and 2). Ireland and Austria are classified as countries with a lower level of the synthetic measure.

Figure 3. Spatial distribution of EU countries according to the level of sustainable development in 2009

Figure 4. Spatial distribution of EU countries according to the level of sustainable development in 2019

In the case of countries that joined after 2014, Bulgaria deserves attention as it was among the countries with the highest level of sustainable development. On the other hand, Estonia, Cyprus, and Slovakia are at the other extreme.

After 10 years, however, there are evident changes in the distribution of individual typological groups. In 2019, the countries belonging to the first and second typological groups were located primarily in the northern and central parts of the European continent. There have been significant changes in the classification of individual countries. A high increase in the position was recorded for Austria and Malta, which advanced to the 1st typological group from 4 and 3, respectively. Positive changes in the level of sustainable development were also noted in the case of Slovenia, the Czech Republic, Hungary, Estonia, Ireland, and Cyprus.

A decrease from the second to the fourth typological group occurred in the case of Bulgaria, France, and Romania. In addition to the three mentioned, a deterioration in the level of sustainable development was recorded for six countries: Sweden, Italy, Poland, Belgium, Spain, and Lithuania.

The sources of such significant changes in the level of sustainable development should be sought in the changes in the value of three indices: I_1 – environment, I_2 – society, I_3 – economy. Figure 5 shows the evolution of the average normalized values by years and groups of variables.

The information presented in the figure shows that in the analysed period, the indicator's value relating to the economic aspect of sustainable development decreased – from 0.70 in 2010 to 0.54 in 2019. A clear positive tendency was noticeable for the social indicator – an increase from 0.45 in 2009 to 0.54 in 2019. In the case of the indicator defining the environmental aspect of sustainable development, there is a reversal of the downward trend from 2009 (0.47) to 2015 (0.42) and a slow increase to 0.45 in 2019.

In the further part of the study, based on the values of the I_1, I_2, and I_3 indices determined for each country in 2009–2019 and the previously built fuzzy model, three sustainable development scenarios were constructed: pessimistic average and optimistic. In the case of the first of them, the minimum values of each of the three indices for all the objects of the study (EU countries) are included in the modelling. The second variant took into account the average values of the indices, and the third one – the maximum values. The results are presented in Table 4.

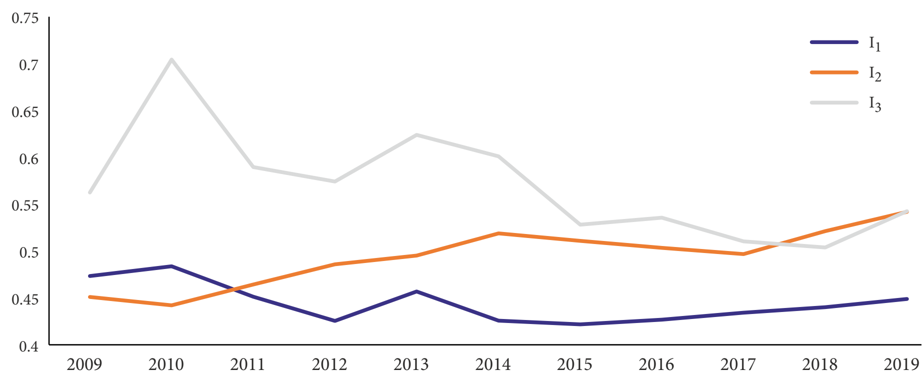

Figure 5. The average values of normalized indicators: environment, society, and economy by years

Table 4. The values of the synthetic measure for the pessimistic, average, and optimistic scenarios

no.	Countries	scenario		
		pessimistic	average	optimistic
1	Belgium	0.277	0.392	0.666
2	Bulgaria	0.194	0.646	0.806
3	Czechia	0.325	0.444	0.601
4	Denmark	0.528	0.705	0.795
5	Germany	0.318	0.482	0.677
6	Estonia	0.250	0.351	0.612
7	Ireland	0.331	0.489	0.630
8	Greece	0.217	0.398	0.448
9	Spain	0.275	0.387	0.650
10	France	0.209	0.429	0.791
11	Croatia	0.261	0.439	0.796
12	Italy	0.486	0.575	0.621
13	Cyprus	0.194	0.376	0.535
14	Latvia	0.441	0.641	0.800
15	Lithuania	0.194	0.293	0.643
16	Luxembourg	0.479	0.545	0.634
17	Hungary	0.279	0.434	0.713
18	Malta	0.213	0.573	0.748
19	Netherlands	0.581	0.725	0.790
20	Austria	0.199	0.592	0.804
21	Poland	0.319	0.572	0.787
22	Portugal	0.367	0.429	0.491
23	Romania	0.200	0.432	0.806
24	Slovenia	0.535	0.686	0.787
25	Slovakia	0.205	0.200	0.360
26	Finland	0.414	0.668	0.802
27	Sweden	0.371	0.630	0.786
28	United Kingdom	0.320	0.393	0.484

In the pessimistic variant, despite the assumption of the minimum values of indices I_1, I_2, and I_3, the average level of sustainable development ($U \geq 0.5$, see Table 1) was achieved by three countries: The Netherlands (0.581), Slovenia (0.535) and Denmark (0.528), and four more were close to reaching this level: Italy (0.486), Luxemburg (0.479), Latvia (0.441) and Finland (0.414).

At the same time for as many as 10 countries: Estonia (0.250), Greece (0.217), Malta (0.213), France (0.209), Slovakia (0.205), Romania (0.200), Austria (0.199), Lithuania (0.194), Cyprus (0.194) and Bulgaria (0.194) recorded values of synthetic measure $U \leq 0.25$ (see Table 1), which means that minimal development in the spheres of environment, society and economy would negatively affect their level of sustainable development.

In the average scenario, for 10 countries: Luxemburg (0.545), Poland (0.572), Malta (0.573), Italy (0.575), Austria (0.592), Sweden (0.630), Latvia (0.641), Bulgaria (0.646), Finland (0.668) and Slovenia (0.686), synthetic measure values *U* clearly exceeded the level of 0.5 (see Table 1), which means the achievement of the average level of sustainable development. In the case of Denmark (0.705) and the Netherlands (0.725), values close to 0.75 suggest that their level of development should be assessed as high.

The following 8 countries can be classified as countries with a level close to the average: Ireland (0.489), Germany (0.482), Czech Republic (0.444), Croatia (0.439), Hungary (0.434), Romania (0.432), Portugal (0.429) and France (0.429). Despite the average values of the I_1, I_2, and I_3 indices, the levels of sustainable development in Slovakia (0.200) and Lithuania (0.293) should still be assessed as low.

When analysing the optimistic scenario, we notice that 12 out of 28 countries have achieved a high level of sustainable development. These include: Romania (0.806), Bulgaria (0.806), Austria (0.804), Finland (0.802), Latvia (0.800), Croatia (0.796), Denmark (0.795), France (0.791), Netherlands (0.790), Poland (0.797), Slovenia (0.787) and Sweden (0.786). Malta (0.784) and Hungary (0.713) were close to reaching the level of 0.75, and, also in their case, it should be assumed that they have reached this level.

10 countries: Germany (0.677), Belgium (0.666), Spain (0.650), Lithuania (0.643), Luxembourg (0.634), Ireland (0.630), Italy (0.621), Estonia (0.612), Czech Republic (0.601), and Cyprus (0.535), exceeded the level $U \geq 0.5$ which means that in the most optimistic scenario they reached the average level. The following countries were close to its achievement: Portugal (0.491), Great Britain (0.484), and Greece (0.448).

Against this background, Slovakia was clearly distinguished (0.360), whose level of sustainable level is between low and average.

4. Discussion

Attempting to measure the level of sustainable development is a complicated task. The reason for this is the very broad specificity of the issue, covering not only the economic, social, and environmental spheres. Therefore, one of the most important elements influencing the classification result is selecting the original set of variables for the study and the degree to which it covers the above-mentioned spheres. Comparing the results presented in this article with other studies devoted to measuring the level of sustainable development in the EU Member States suggests some similarities and differences.

When comparing the value of the synthetic measure with the values of the SDG (Sustainable Development Goals) index for 2019 (Sustainable Development Solutions Network and Institute for European Environmental Policy [SDSN & IEEP], 2019), built based on approximately 113 indicators, some common features are noticeable, mainly concerning the spatial distribution of its values (Figure 6).

The comparison of the information in Figure 4 and Figure 6 shows that countries with high levels of both measures are concentrated in the northern and central part of the continent, and with lower levels of measures – in the south of Europe and on the Balkan Peninsula. Despite these similarities, the linear correlation coefficient indicates a moderate (0.484)

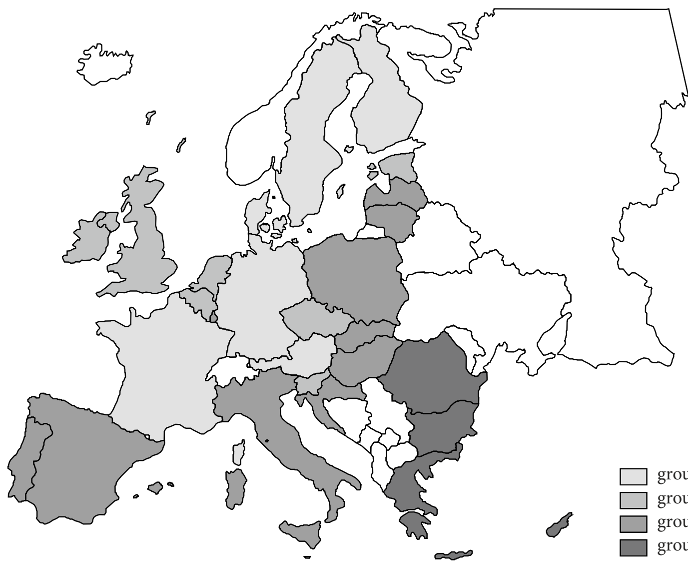

Figure 6. Spatial distribution of EU countries according to the SDG index in 2019
(source: own elaboration based on SDSN and IEEP, 2019, p. 3)

similarity between the values of the SDG index and the synthetic measure calculated based on the fuzzy model in 2019. This difference results mainly from the different numbers and scope of the variables.

A similar degree of similarity (correlation score 0.46) was obtained from the analysis of the rankings of EU countries built using the TOPSIS and VIKOR methods for 2016 and presented in the work of Piwowarski et al. (2018).

On the other hand, a comparative analysis of the assessments of synthetic measures presented in (Grzebyk & Stec, 2015) for the years 2009–2012, and built with the use of 10 economic-social-environmental indicators, indicate a low degree of similarity, the correlation coefficients were assessed for the following years, respectively: 0.29, 0.23, 0.14 and 0.15. A similarly low value (0.15) was recorded for the synthetic measure for 2013 presented in the paper by (Balcerzak & Pietrzak, 2016).

It is difficult to find in the literature a study which, apart from estimating the average value of the synthetic measure of the sustainable development level for individual 28 EU countries, analyzed the scenarios (optimistic, average and pessimistic) for each country. Kiselakova et al. (2020), using the zero unitarization method, conducted a study aimed at comparing the total value of the synthetic measure of sustainable development for each EU country. The study was mainly based on Eurostat data from 2018. The results of the study are in line with our results. Sweden, Denmark, Finland and Austria are among the leaders in terms of sustainable development. The countries with a medium level of sustainable development include Poland, the Czech Republic, and the weakest countries are Romania, Bulgaria, Greece and Cyprus. Grzebyk and Stec (2015) obtained corresponding results from their study utilizing data from 2005–2012. The highest values of synthetic measures were achieved by Sweden, Latvia, Finland, Denmark and the Czech Republic, while the lowest by Malta, Cyprus, Romania, Greece and Slovenia.

Bluszcz (2016) used the aggregated indicator of sustainable development to compare the level of sustainable development of individual European Union countries. The analysis was based on the data from 2012. The study shows that Luxembourg, Ireland, Sweden and Austria were the countries with the highest level of sustainable development. The lowest values of the aggregated indicator of sustainable development were recorded for Greece, Romania and Bulgaria. Janković et al. (2016) ranked countries by the level of implementation of the strategy for sustainable development. Luxembourg, Sweden, Filnadia, the Netherlands and Denmark turned out to be the leaders in the ranking. The worst countries in the ranking were Romania, Bulgaria, Lithuania, Latvia, Croatia and Hungary.

Kasztelan (2017), based on the analysis of 33 selected indicators of the "green economy" from the OECD database, showed that green growth can lead to the solution of economic and environmental issues that are part of the concept of sustainable development. The highest scores in terms of "green economy" were given to Denmark, Germany and Sweden. On the other hand, the countries with the lowest level of green growth are Bulgaria and Cyprus (Kasztelan, 2016). Similar research conducted in 2018 showed that Sweden is the leader in terms of green growth. The countries with the lowest greening of the economy were Greece, Malta, Bulgaria and Cyprus, which is in line with our results (Kasztelan, 2018).

Conclusions

The article is based on a fuzzy model to construct synthetic measures characterizing the level of sustainable development in EU countries in the years 2009–2019. The synthetic measures were built on the basis of the features assigned to the three pillars of sustainable development, i.e., the environmental, social, and economic ones. The article focuses on the role of state and public policies in achieving sustainable development; hence the tax and expenditure policy, as well as debt, is strongly reflected in the analyzed features, including the share of environmental taxes in total taxes, the level of public debt, R&D spending, social spending. The new research approach includes financial variables – a deficit, a debt, environmental taxes, and public expenditure in the study. As a result of the analyzes, four typological groups of countries were obtained: the first group of countries with the highest level of sustainable development, the fourth group of countries with the lowest level of sustainable development, and groups 2 and 3 of countries close to the leaders (group 2) and with moderate development (group 3). The first typological group includes countries with a high share of environmental taxes in total taxes, with a low level of public debt and characterized by a low level of income inequality, thus effectively implementing the policy of budget redistribution. The second typological group includes countries with a high level of regional development, however, with higher debt ratios than the first group. The third group includes the countries of Central and Eastern Europe and Great Britain, Belgium, and Greece, while Slovakia, Lithuania, and Spain are in the fourth typological group. As a result of the analyzes, it turned out that sustainable development is favored by a sustainable public debt policy and a tax policy aimed at increasing the share of environmental taxes in total taxes. At the same time, countries whose level of social and R&D spending was higher than the average also recorded a higher level of sustainable development. An important aspect is also the redistribution policy favoring the equalization of income inequalities. In order to assess the possible impact of the analyzed public policies, the article analyzes scenarios with the use of fuzzy simulations. It was examined which ranking positions and values of the aggregate measure would be achieved by individual countries under the optimistic and pessimistic scenarios. In the optimistic scenario, it was assumed that a given country in the long term implements the values of variables at an optimal level, taking into account the experience from previous periods covered by the analysis. In the pessimistic scenario, it was assumed that a given country implements the least desirable values of the variables that appeared in its statistics in the past. The scenario analysis showed that if the countries with the highest deficit and debt levels were able to maintain the lowest debt value they had in the past in the long run, they would improve their places in the sustainable development ranking and be promoted to a higher typological group, e.g., the example of Italy. Similar results concern the ability to maintain the dynamics of R&D spending (including Romania) or pro-social spending and increase the share in environmental taxes. As a result, it can be concluded that effective public policies (tax, expenditure, debt) impact the dynamics and the level of sustainable development of the surveyed countries, and sustainable public finances can be a tool supporting the implementation of this development. The findings of our study may be valuable for policy makers how to support the growth and dynamics of sustainable development of the country through public policy tools. The results of the research can be used by decision-makers responsible for public policies supporting the implementation of SDGs. In particular, it concerns such elements of fiscal policy as public debt or shaping public revenues and pro-environmental attitudes of market participants through the environmental tax system. Sustainable debt management should include financing, the so-called impact investment, assuming the selection of public expenditure in the so-called green procurement or – more broadly – sustainable procurement, and follow the rule of intergenerational responsibility for debt. It is also important to use hard and soft budget constrains in the context of sustainable debt management. An important role plays also the redistribution policy focused on social inclusion (in particular through instruments such as grants and public transfers) as well as sustainability and social policy aimed at levelling income inequalities, providing social inclusion to people at risk of negative social phenomena, e.g. poverty, and preventing social exclusion. At the same time, it is important to shape the entire range of policies supporting sustainable growth, e.g. innovation policy supporting solutions in the field of innovation, renewable energy sources or energy transformation, sustainable transport policy, policies in the field of sustainable cities and communities.

The authors of the study are aware of the limitations of the study, manifested, inter alia, in the access and comparability of data, and adopted methodological assumptions. Future research is planned to be carried out in greater detail for a more significant number of variables and separately for each typological group.

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Author contributions

Concept: M.Z.; methodology: I.B., M.O.; software: I.B., M.O.; validation: I.B., M.O.; formal analysis M.Z., I.B., A.S., M.O.; investigation: M.Z., I.B., A.S.; resources: MZ. I.B., A.S., M.O.; data curation: I.B., M.O.; writing original draft preparation: M.Z. I.B., A.S., M.O.; writing review and editing: M.Z., I.B., A.S., M.O.; visualization: M.Z.; I.B., A.S.; supervision: M.Z.; project administration: M.Z.; funding acquisition: M.Z.

Disclosure statement

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