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ALIGNMENT OF CIRCULAR ECONOMY BUSINESS MODELS FOR FRAMING NATIONAL SUSTAINABLE ECONOMIC DEVELOPMENT

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Abstract
Circular economy offers opportunities to boost jobs and tackle climate change. The article reflects aspects of the impact on the environment through sectoral policies to support the circular economy because current business as usual model, based on the linear economy principle leads to a staggering inefficiency in nature resources are managed, with increased pollution, loss of ecosystems and substantial losses of value with each product disposed. This requires a change not only in consumer behaviour but even more on the resource extraction and material production side. The purpose of the research paper is to develop a decision-making matrix providing a step-by-step approach for the policymakers.

Keywords
business models; circular economy; systems dynamics; sustainability.

Introduction
As the economy experiences significant boost, which will be such also in the long run, more and more primary materials for the production purposes are required and they inevitably have a significant impact on waste generation. There is no problem if the economy is relatively small compared to the natural ecosystem. But it is

essential to keep in mind that natural ecosystem is simultaneously the source of raw materials and the final disposal for human-produced wastes. Although the result of non-rational resource consumption determines the need for increased opportunities for the implementation and expansion of recycling and reuse of products, especially in developing countries with a high population density [1–4]. All this is describing the business-as-usual model, which has been applied worldwide in the 20th and 21st centuries and can be defined as linear economy. The core of the linear economy is the chain of "resource extraction - production - use - profit making - waste management at a lower cost,", which has led to increase of short-life span use products with considerably low percentage of recycling.

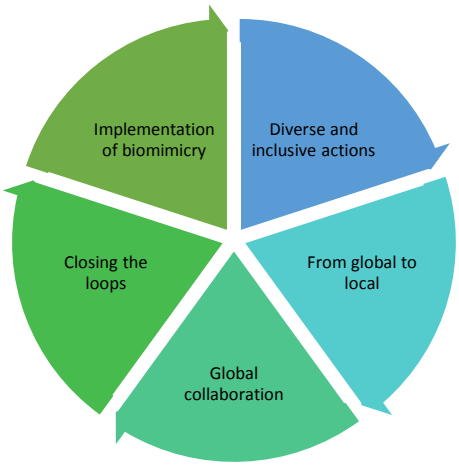

Figure 1. Steps to minimise the circularity gap.

Building a global coalition for action that is both diverse and inclusive, will bring together business, governments, NGOs and scientists to boost capacity to serve societal needs and to solve problems more sustainably. By closing the loops, it will be possible to monitor the resource flow and to identify the recycling or industrial symbiosis opportunities [5–8]. Implementation of biomimicry allows assessing nature not for consumption purposes, in terms of what can be extracted, harvested or domesticated, but for learning and optimising in production processes.

The theoretical framework

The circular economy approach is based on a system of production, distribution of consumption, reuse, recycling in order to save the cost of products and minimize the generation of waste to reduce the burden on the environment through the 3R (Reduce-Reuse-Recycle) Concept [9–12]. The circular theory uses different models that can be used within their functional purpose. The need to develop a national model of a circular economy is linked closely with the specifics and strategy of transition from a linear economy with appropriate financial incentive measures to achieve environmental criteria in all areas of production. Pollin, et.al. [13] investigated the conditions for such a shift from linear to circular economy that can be developed and implemented within the green recovery package.

The development of a natural ecosystem in terms of rational resource consumption, recycling and reuse of products as new business models has been identified and analysed [2,4,7,14]. Obviously, transition to a circular economy is not possible without the support of the authorities at the national, regional and municipal level, which can be implemented through sectoral policies to finance waste minimisation and recycling [15]. Increasing the efficiency of consumption of natural resources is possible with the technological modernization of the economy, the transition to higher technological structures and the improvement of legal regulation of the circular economy [16].

The circular economy is a field of emerging research, and up to now, the focus has mostly been on materials and the circularity aspects of the companies [17–19] investigated the transition to circular economy in order to reduce the overall anthropogenic load of the economy on the environment. This approach considers the linkages within and between sectors / value chains.

According to Scarpellini et.al. [20], circular economy-related activities introduced by businesses are influenced by the analysed capabilities that also improve the environmental and financial performance of firms in a circular economy framework. Moreover, the researchers show the mediating role of stakeholders in introducing

the circular economy in businesses, which is a little explored line of inquiry, as this relationship has not been widely analysed for the circular economy. When analysing the theoretical framework trends, it can be clearly noted that research on circular economy generally focused on the production aspects, paying less attention to consumer behaviour and demand [21].
It has been identified, that sustainable business models are able to provide and sustain environmental, societal, and economic value [22–24]. Circular business models are aimed at identifying and assessing the logic of creating circular infrastructure [25]. In addition to that, they tend to focus on resource efficiency strategies in order to develop more sustainable production and consumption patterns [26].

Methods
Studies have shown that the development of a marketing strategy for an enterprise is carried out according to almost the same scheme (Figure 4). However, the study showed that customers had changed dramatically: first, they are interested in a personal attitude, and only then in the quality of goods, price – the usual indicators that have always been in the first places.
Thus, we believe that the main goal of a marketing strategy for an enterprise's financial growth is to ensure customer loyalty, i.e., customer focus.

Results
It has been identified that both governmental and non-governmental organizations increasingly encourage the businesses for the transition towards a circular economy. The EU Action Plan has been strengthened by revising the waste package directives, which has succeeded in 2018, altogether forming the Circular Economy Package with the aim of developing the circular economy through the creation of various platforms, offering funding from the Cohesion Fund [15,27].
The main outcome of the strategies is to implement the paradigm from linear to a circular economic model. Establishing this kind of a shift is a complex task which requires substantial changes in habits and practices in many fields of society[28]. This leads to a conclusion, that each strategy is able to define different objectives in relation to the general aim.
It is very important that for the Stakeholders there is a possibility provided to communicate and share experiences and best practices via the European Circular Economy Stakeholder Platform. This platform was established in 2017 by the European Commission and the European Economic and Social Committee with the main aim to enhance the circular economy both across territories, industries and communities by bringing together experts and providing possibilities to share knowledge and foster dialogue [29].
The latest reports by European Commission reveal that in 2019 there were already over 30 Circular economy strategies in place, both of national and/or regional levels. Despite the level the key concept of the strategies is to contribute to the so-called paradigm shift of moving from the linear towards a more circular economic model. Establishing this type of a shift is a complex goal requiring fundamental changes in consumer behavior and habits in many subsystems of society.
The transition to a CE requires systemic change and a holistic, integrated approach that takes into account links within and between sectors, within and across value chains and between civil society and industrial stakeholders [18].
It is important to understand that circular economy can be applied by an entity by adoption of certain business model, or by transformation of existing activities or business elements. Below the authors have summarized the business aspects that can be improved by implementation of circular economy aspects.

<u>Types of Circular economy business models.</u>
The use of different business models allows you to minimize the consumption of materials and resources for production, as well as complete the life cycle of products through further processing and are based on:

- circular supply models. These substitute materials from primary resources with renewable, bio-based, or recovered materials, in this way reducing demand for primary resource extraction.
- resource recovery/regaining models focus on recycling waste into secondary materials (or secondary raw materials), consequently, diverting waste from landfill and in addition decreasing the volume of extraction of primary resources.
- product lifetime extension models. Focus on extending the consumption period of products, slowing the flow of materials in the economy and reduce the rate of primary resource extraction, consumption, and waste generation.
- sharing models. Tend to facilitate the sharing of goods, and can therefore reduce demand for new

products, optimize use of products already owned by the end-user and reduce the consumption of primary natural resources.

- product service system models. It is where services, not products are placed on the market, thus improving stimulus for green product design and more effective product use, thus contributing a more sustainable use of primary resources [30–32].

Table 1. Summary of actions, that may be implemented in different entity's divisions.
Source: based on [4,5,14–23,6,24–29,33,7–13].

Entity division	**Improvements to be undertaken**
Human resources	organizational culture oriented towards recycling, reuse; training and improvement of the personnel consumer behaviour, in line with circular economy
Logistics	closing the loops; implementation of reverse logistics;
Research and Development	Reduce consumption of non-renewable primary resources; increase consumption of renewable primary resources; reduce carbon emissions; reduce waste; implementing internet of things
Production	developing products with a longer life cycle; developing products suitable for reuse, remanufacturing; optimization of production equipment; implementation of industrial symbiosis; extension of technical quality control
Sales and After-sales	improving consumer relations; developing cooperation, transparency between stakeholders; after-sales services; increasing producer responsibility for ineffective use of primary resources, environmental pollution
Financial sector	identifying and optimising environmental costs; implementing accounting in accordance with the circular economy; retaining economic value of the materials

Following table shows a summary of most popular circular economy business models, as well as highlight types of resource efficiency, business model sub-types and reveals sectors, which are already implementing circular economy business models. For instance, circular value chain stands for reduced consumption of primary resources in production and uses renewable, recycled or recyclable materials. Material recovery and industrial symbiosis - tracks and recovers products before they become waste, enhances effective use of by – products and is focused on recycling up-cycling and down-cycling. Product durability, repair is focused on product life cycle extension and development of "dismantling design" at the design stage.
Personalization and tailor-made design – offer building long-term relationships with the client, promotes loyalty, makes it easier to develop repair, material recovery and recycling, and last, but not least - stands against overstocking. Product service system, dematerialization of services – grants access to a service, not to the goods themselves and it shifts the mindset from owning to using products. And finally – sharing economy – means that citizens have more opportunities to rent, lease, share, exchange or lend goods. It does help in optimization of the production rates and offers a variety of platforms for product sharing, exchange or lease.
When analyzing types of product services, three main types can be identified. Product-oriented: the business model is focused on sales of products. Some extra services can be added, as for example maintenance services. Use-oriented: The product still is a key player; it is owned by a producer-company and is offered to a customer.

The idea behind this category is to provide access to the product for the user. Result-oriented: The customer and service provider agree on a result. Normally there is no pre-determined product involved. This is also referred to as a "performance" model [34–36].

The Figure 2 depicts three different categories of product-service business models:

- product-oriented: the business model is focused on sales of products but with additional services for instance, a maintenance contract
- use-oriented: The product still plays a central role. It is owned by a provider but is being made available to the client. This is also referred to as an "access" model. Basically, it grants consumer access to the functionality of the product, when required by consumer.
- result-oriented: The consumer and provider agree on an outcome, within this business model, the product, delivering the outcome is not much important for the consumer. This is also referred to as a "performance" model [24].

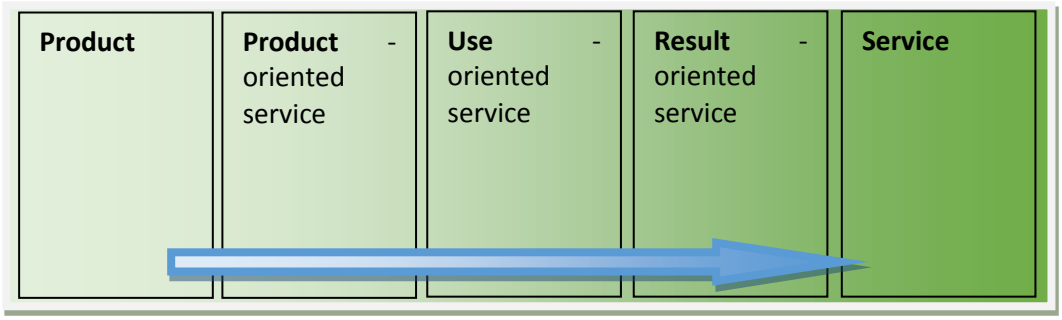

Figure 2. Transition from Products to services in circular economy.

This will be one of the most important tasks for the entities in the nearest future – to identify their status-quo and to understand transition towards what direction would be most appropriate, sustainable and economically efficient for the company.

Decision-making process.

In order to be able to assess all the aspects of the business environment and the entity, it is important to analyze the influential factors, the limitations and the particular required data for each company or business sector [37–39]. According to the abovementioned, the authors have developed an information flow for decision-making process for assessment of transition to circular economy and for choice of best appropriate business model, which is presented in the Figure 4.

Regulatory changes in many cases are seen as keys to unlock the existing circularity potential. Legislative boundaries can add a positive impact to the value chains and encourage cooperation between different economic sectors that might have not evaluated this cooperation possibility beforehand. In some cases, it is related to technical issues that affect material flows in different sectors, especially here comes the issue of the legal definition of waste and certain waste treatment obligations.

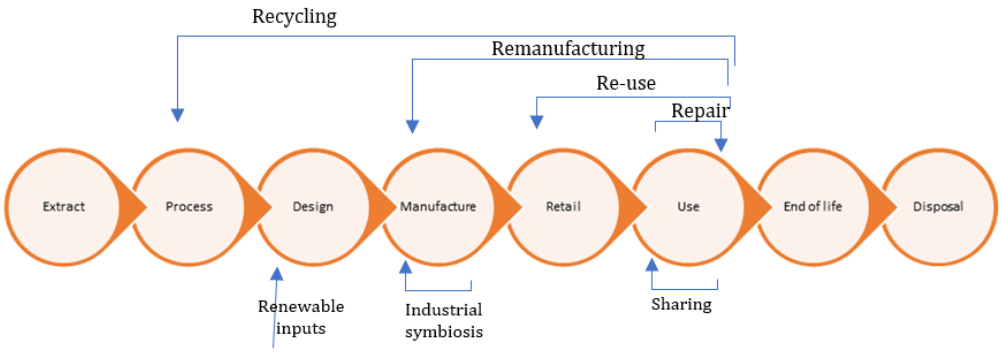

Figure 3. The impact of circular economy on linear business processes. *Source [40].*

This type of examples mostly requires actions to be taken on national or European level. A discussion of regulation framework in circular economy strategies may concern advocacy, rather than direct legislative innovation.

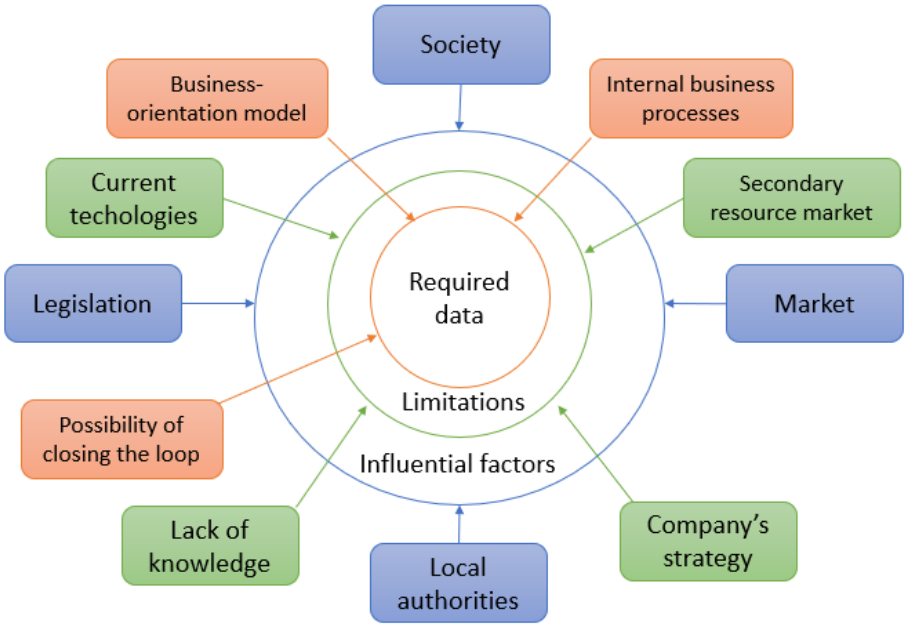

Figure 4. Information flow for decision-making process.

Assessment of business values and closed-loop approach.

In this section, the authors would like to tackle the importance of the closed-loop, identifying it a bit broader that solely on a company-scale. The figure below depicts three main basic principles for a company/region/State economy to implement the closed-loop concept.

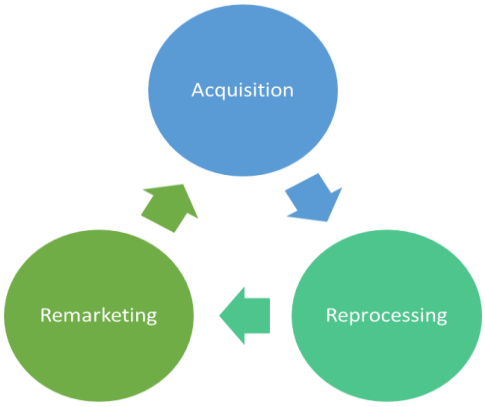

Figure 5. The main business processes for closed-loop system.

First step is acquisition. It means that one needs to develop a collection system to collect the right volumes of materials or products of the right quality, for a competitive price.

Second step is reprocessing. At this stage refurbishment, remanufacturing or recycling of used products or materials, for a competitive price has to take place.

Third step is remarketing. Finally, one requires to identify markets that would be ready to purchase the reprocessed products or materials.

Here the utmost importance is to have the comprehension that in case any of these steps fails, the closed loop is not there anymore.

Since the circular economy highlights the importance of value creation for all stakeholders, this is a very important perspective to take. Based on an examination of value, the parties involved can develop a model for the optimization of common value creation [41–43]. After undertaking an extensive literature research, the

authors have gathered business values that can be obtained from the implementation of closed loop principle (Table 2).

Table 2. Assessment of circular economy business values. *Source: based on Vijayan, et. al. [43] Camilleri [44].*

Type of value	**Description**
Sourcing value	Direct cost reductions and savings that can arise from closed loop business practices
Environmental value	Benefits that result from improved ecological footprints, i.e. ease of compliance and improved green image
Customer value	Increased customer loyalty, better customer satisfaction and superior brand protection
Informational value	Closing the loop generates valuable data on production and supply problems, failure rates, useful lifetime of the product and usage patterns.

Matrix for circular economy strategy of a country's economy.

As a result of the research, the authors offer a step-by-step matrix for development of a tailor-made circular economy strategy for a country's economy. Main key points of the matrix are – to assess the stakeholders at the following stages: material extraction, material processing, product design, manufacturing, distribution, repair, refurbishment, remanufacturing, waste management. It should then be followed by development of key stakeholder working group (KSWG).

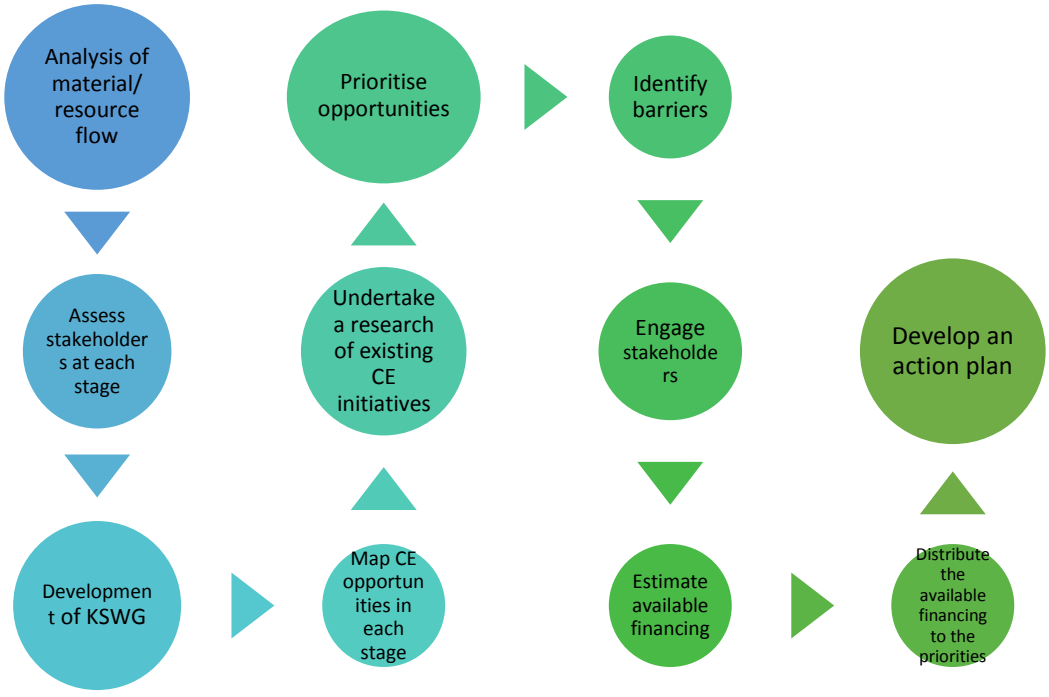

Figure 6. Circular economy action plan development matrix.

This working group then will have a range of very important obligations. One would be thorough assessment of each economy field in order to identify the best practices in the circular economy that are already in place [44–46].

Another – wise and sustainable distribution of allocated financing to the priority stages. As a result of the KSWG work, an action plan will be developed. Further it is of vital importance to hold a range of seminars for the stakeholders and industry to communicate on the priorities, financing available and required compliance criteria.

The circular economy can be an important lever to achieve key policy objectives such as generating economic growth, creating jobs, and reducing environmental impact. Multiple studies have already demonstrated how the circular economy can contribute at a national, regional and supranational level to objectives such as generating economic growth, creating jobs, and reducing environmental impact [47]. While using different methodologies and performed on different sectoral and geographical scopes, these studies have consistently demonstrated the positive impacts of the circular economy: growing GDP by 0.8–7%, adding 0.2–3.0% jobs, and reducing carbon emissions by 8–70%.

Impact

The necessity to shift to circular economy can be boosted when the entities would be shown the possible business models and the way one or another company might apply them on practice. The purpose of the research paper is to develop a decision-making matrix providing a step-by-step approach for the policymakers. This tool would allow identifying the best suitable circular economy business model for Latvia's economy in general – i.e., which direction of the circular economy should be given more support on the state level. The methods used in the paper will be economic assessment, secondary data analysis and systems dynamics for decision-making. The research is limited to analysis of circular economy examples in Latvia. One of the main findings as well as practical implication will be a tool for decision-making basing on authors developed circular economy business model choice matrix. The research will be of a value for entrepreneurs, working with the focus on the circular economy alongside for policymakers, to identify the sectors of economics with the higher potential for transition to circular economy. The paper is designed as a research paper. These studies are the blueprints to prove the environmental and social impact of circular economy. Apart from this the positive impact of a circular economy on GDP growth, job creation and carbon reduction, there are also cost savings and increased reuse and recycling of materials through reduced demand for primary materials.

Conclusions

Basing on the undertaken research, the authors have developed the following conclusions.

The concept of circular business models is seen as a strong enabler for companies that are willing to move forward circular practices. However, it has to be understood that designing business models in line with circular economy principles and capitalising the environmental and economic values of a company or a product lead to development of a new set of requirements for business model innovation. Business models need to be designed in a way that enable preservation and utilisation of the value embedded in resources (e.g. through resource recovery, long life, multiple use cycles) if resource loops are to be slowed and closed.

As a result of this research the authors have developed a matrix for circular economy strategy of a country's economy. By applying this step-by-step approach, policymakers will be able to develop most inclusive action plan, that will assess and take into consideration all the fields of economy tackled by circular economy, it will identify already existing circular economy initiatives and prioritise the opportunities at each of the circular economy stages.

Further research

Further research would be linked with practical development of part of the action plan matrix, by assessing stakeholders at each stage of circular economy, developing the opportunities and identifying the barriers to the implementation of circular economy.

It is of interest for the authors to undertake further research and to assess the resource cycle within a company, to develop cost comparison, with and without implementation of circular economy elements. In this case it would be assessment of implementation of industrial symbiosis.

Conflict of interest

There are no conflicts to declare.

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COOLING AND HEATING OF THE FLUID IN THE CYLINDRICAL VOLUME

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Abstract
Experimental studies of the non-stationary heat exchange in the system «environment I – body II» have been carried out. It is established that in the body II, which consists of the fluid and thin-walled metal envelope, the characteristic features of the regular thermal mode occur, i.e., cooling (heating) rate of the body II- m = const; heat transfer coefficient between the water (environment I) and body II is practically stable α_1 = const; uneven temperatures distribution coefficient in the body II ψ = const.
This new notion of the heat transfer regularities in the body II is planned to apply for further development of the experimental-calculation method for the forecasting of the heat exchange intensity in the compound fluid media with limited information regarding thermophysical and rheological properties.

Keywords
non-stationary heat exchange; regular thermal mode; cooling (heating) rate; heat transfer coefficient; uneven temperatures distribution coefficient.

Introduction
For the sustainable development of the economy with minimal pollution of the environment it is expedient to construct a chain of enterprises according to the requirements (recommendations) of the UNO. Waste of the first enterprise may be used as the input materials for the second enterprise, waste of the second – input for the third, etc. It is known that the organization of the technological processes is possible only on the conditions of corresponding thermal stabilization of these processes. In general case, operating media in the reactor of the biogas units (BGU) are liquid, heterogeneous mixtures of the organic waste of different processing plants, crop farming, livestock farming, in certain cases they may represent three phrases coarsely dispersed colloid systems on the aqueous base, i.e., compound fluid mixtures (CFM). The existing testing facilities for the experimental studies of the heat exchange in the technological equipment are cumbersome, expensive

and require much time for carrying out multivariate studies [1–3]. The research, dealing with the study of heat exchange intensity in liquid organic mixtures for BUR, aimed at final practical result [4–8], for instance, heat exchange intensification, are known. More profound study and understanding of heat exchange processes is not only of practical importance but it has great impact on the selection of the research process direction, search of general regularities of research, broadening knowledge regarding heat exchange liquid organic waste. Taking into consideration, mentioned above new method of the heat exchange intensity forecast is suggested [9–14], where such notions as «model», «partially-model», «virtually model», «calibrating» fluid (further in the text «auxiliary fluids») and basic experimental testing facility are used [10,11]. Below in the text this method is called «experimentally–calculation method of the compound fluid mixtures (ECM)».

In the elements of the experimental testing facility ECM the intensity of the heat exchange in the compound media of the real technological processes is determined. Calibration is carried out on the fluids with known thermal physical properties (TPP), such as water, sugar solution of different concentration, glycerin, sunflower oil, etc., further in the text – «auxiliary fluids». Criterial equations of the heat exchange regularities in the elements of the basic experimental bench are specified, using «auxiliary fluids»[10,11]. Further improvement of the methods of the results analysis in the conditions of the «auxiliary fluids» application is required.

In the studies of the non-stationary thermal mode on the conditions of the conjugate problem [15] regular thermal mode (RTM) is established and analyzed in the bodies: metal ball, placed in thermal insulation envelope; solid ball of the simplest form, placed in the thin envelope of the uniform thickness; ball, made of thermal insulation material, placed in metal; ball, cylinder, disk, made of thermal insulation material, placed in metal envelope; ball, made of metal, placed in thermal insulation material; two-part plates of the symmetric structure; two-part balls of the symmetrical structure; infinitely long two-part cylinder with the metal core and envelope, made of thermal insulation material; ball metal core, placed in thermal-insulation envelope; metal plates, coated with thermal insulation material, three-part body, made of two metals, separated by thermal insulation material. Main connections, existing between the cooling (heating) rate of the solid body m, on one hand, and physical properties of the body, its form, dimensions and cooling conditions – on the other hand, are determined [15]. This enabled to develop methods of the approximate calculation of non-stationary temperature fields, methods of modeling of non-stationary processes in complex objects, evaluate the non-uniformities of the temperature fields at different conditions. On the base of the theory of the regular mode [15–18] new methods of determination of thermophysical properties, gained wide spread occurrence: thermal conductivity coefficient, conductivity, heat capacity coefficient, heat transfer coefficient. Advantages of these methods are simple experimental procedures, high accuracy of the obtained results and short duration of the experiment.

Developed methodical support, for the processing and analysis of the experiment with compound fluid medium and “auxiliary fluids” requires a great number of the experimental results [12,13]. In the given research the method of non-stationary heat exchange process was taken for study on the basis of the following reason [17]: processes are fast flowing, they do not require much time for the preliminary holding at the pre-set temperature; measurements of thermal parameters of the fluid media occur at minor temperature changes, this improves the reliability of the results; the given method enables to carry out measurements in the conditions of the constant changes of the temperature to certain value; non-stationary methods provide wider possibilities, regarding the choice of heat (cold) source than the stationary methods.

Our preliminary experimental results [19,20] partially showed the possibility of the existence of the regular thermal mode in the system «environment I – fluid environment in thin metal cylinder enveloped (body II)». Comparison of the studied objects with literature data is presented in Table. 1. The conclusion can be made that our results are original and are referred to practically unexplored field. Authors can refer only to their studies of the regular thermal mode in the body II [19,20] which, unlike other bodies represents fluid environment in thin metal cylinder envelope.

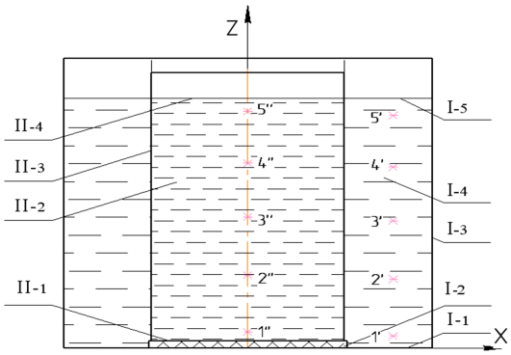
Table 1. Comparison of the objects of the study.

Research, performed by G. M. Kondratiev [15]	**Research, performed by the authors**
1. Regular thermal mode	
1.1 Studied bodies	
Body – solid body, complex of the solid bodies. System: environment (E) I – body	Body II – fluid medium in the cylindrical metal envelope. System: environment (E) I – body II
1.2 Conjugate problem (E – body)	
Newton – Richmann law – Fourier’s law	Newton – Richmann law – Fourier’s law - Newton – Richmann law

Aim of the research: determine the possibility of existing regular thermal mode in the body II on conditions of non-stationary heat exchange in the system “environment (E) I – body II».

Methods

Experimental results are obtained on the test bench, which is the component of the ECM [10]. Figure 1 presents the systems “environment (E) 1 – body II». Water I_{-4}. at the temperature T_1 is poured into the external vessel I_{-3}. Studied substance II_{-2} at the temperature T_2 is poured into the internal cylindrical vessel II_{-3}. Recording of the temperatures in the process of the experiment is performed in ten points, using thermal sensors 1 and 2.



a)

№	X	Z
thermal sensor 1		
1’	70	2
2’	70	27
3’	70	44
4’	70	64
5’	70	90
thermal sensor 2		
1’’	0	2
2’’	0	11
3’’	0	33
4’’	0	52
5’’	0	72

b)

Figure 1. Basic experimental bench: a) Environment I (I_{-1}, I_{-2}, I_{-3}, I_{-4}, I_{-5}); body II (II_{-1}, II_{-2}, II_{-3}, II_{-4}); b) location of the thermocouples on the sensor 1 (1’- 5’) and sensor 2 (1”-5”) relatively the axes x, z, mm

In Figure 1 the environment 1: I_{-1} – metal bottom; I_{-2} – thermal insulation support; I_{-3} – external cylinder with thermal insulation surface; I_{-4} – water; I_{-5} – free water surface. Body II: II_{-1} – metal bottom of the body II, 0.5 mm of the thickness; II_{-2} studied fluid medium; II_{-3} – thin-walled metal cylinder, diameter is 100/99 mm; II_4 – free surface of the studied fluid medium.

Body II consists of the following elements: thin-walled cylinder II_{-3} of the diameter 100/99mm of the finite height which is measured from the metal bottom II_{-1} to the free surface of the studied fluid II_{-4}; metal bottom II_{-1} of 0.5 mm of thickness; studied fluid medium II_{-2}. Free surfaces of the studied fluid II_{-4} and water I_{-5} are located at the same level during the experiment.

Heat exchange of the body II with water I_{-4}, i.e., with the environment, through the lateral external surface II_{-3}, is studied. Minor flows of the heat between the surfaces II_{-4} and I_{-5}, outflows of the heat through the metal bottom II_{-1} are considered in the process of errors determination.

For the processing of the experimental results characteristic curves of averaged temperatures change are presented in Figure 2(a) and 2(b). Averaged temperatures are determined as the arithmetic mean by the results of temperature measurements by the thermocouples, installed at the vertical thermal sensors 1 and 2 (Figure 1) at a certain moment of time.

Heat transfer coefficients $\overline{\alpha_1}$ between the water I_{-4} (Figure 1) and external surface of the thin-walled metal cylinder II_{-3} (Figure 1) and uneven temperature distribution coefficients ψ in the body II according to [15] on conditions of cooling (heating) of sugar solution of b=50%, sunflower oil are calculated, using the experimental data. For this purpose, the processes of cooling, heating of the body II in RTM range are shown schematically in Figure 2(a), 2(b). This range is in time τ_1-τ_n (τ_1 start of RTM, τ_n – end of the experimental study within the limits of RTM). In the given range of cooling (heating) the average value $\overline{\alpha_1}$, and $\overline{\psi}$ is determined, besides, $\overline{\alpha_1}$ and $\overline{\psi}$ in the limited ranges of time τ_{1i} – $\tau_{1(n+i)}$ is determined.

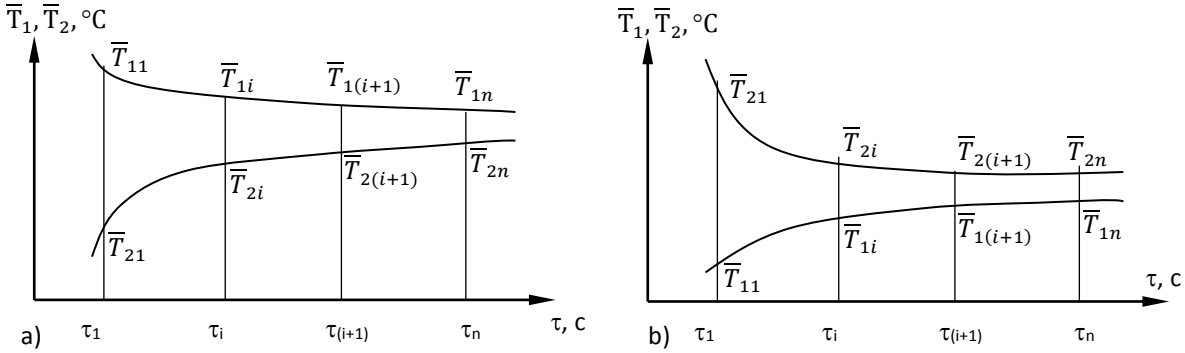


Figure 2. Processes of heating (a) and cooling (b) of the body II in RTM range for the processing of the experimental data of the studied fluid (see Table 3)

Cooling, heating of the sugar solution of the concentration c=50% and refined sunflower oil is studied experimentally. Results of the primary processing of the experimental data are presented in Figure 3.

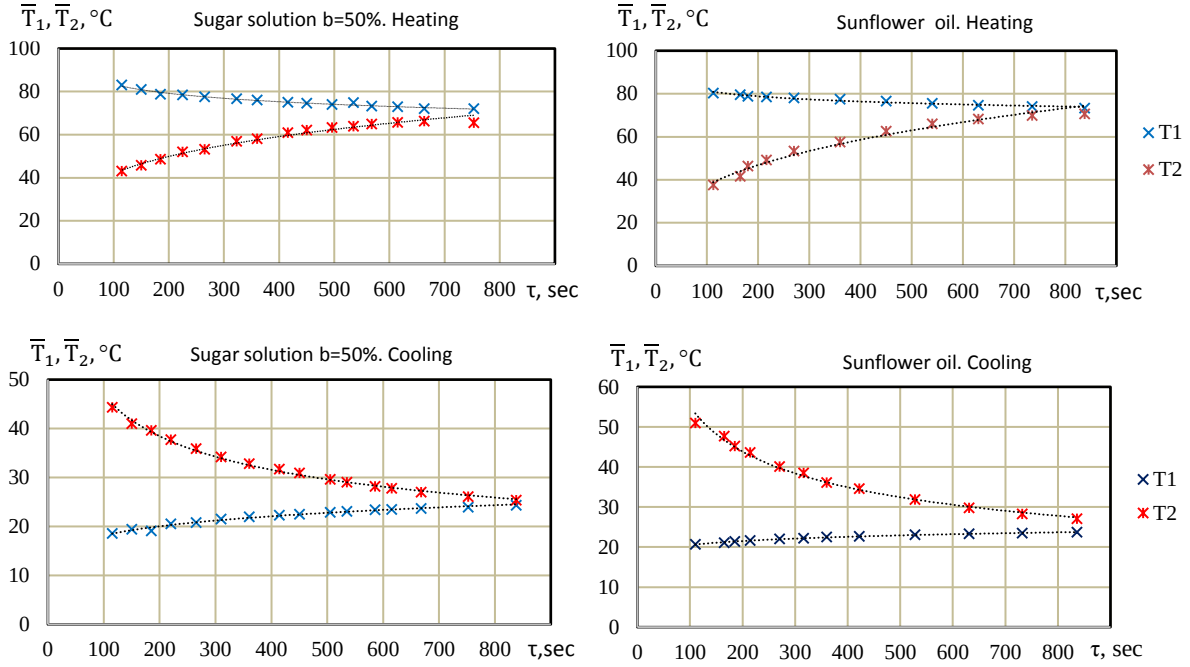


Figure 3. Change of the environment temperature and studied fluid medium in time: $\overline{T_1}$ – volume averaged temperature of the environment (water); $\overline{T_2}$ – volume averaged temperature of the body II.

Real noted range of thermal physical properties change of the studied fluid media is presented in the Table 2.

Table 2. Thermal physical properties of the studied fluid media.

№	Studied fluid	Heat exchange direction	Range of changes of temperature $\overline{\overline{T_2}}$ °C	Coefficient of heat conductivity, λ_2, W/(m·K)	Coefficient of kinematic viscosity, ν_2, m²/c	Density, ρ_2, kg/m³	Specific heat capacity, Cp_2, J/(kg·K)
1	sugar solution b=50%	heating	48-65	0.417-0.434	$(4.8\text{-}7.4) \cdot 10^{-6}$	990-982	4174-4175
2	sugar solution b=50%	cooling	27-25	0.435-0.418	$(9.3\text{-}5.1) \cdot 10^{-6}$	995-999	4173-4174
3	sunflower oil	heating	46-70	0.165-0.163	$(2.82\text{-}1.37) \cdot 10^{-5}$	901-892	2304-2338
4	sunflower oil	cooling	41-30	0.166-0.167	$(3.46\text{-}6.13) \cdot 10^{-5}$	901-911	2351-2219

Cooling (heating) rate m of the body II is determined from the equation, c^{-1} [15]

(1) $$m = \frac{\ln \vartheta_1 - \ln \vartheta_2}{\tau_1 - \tau_2},$$

where ϑ_1, ϑ_2 – is excessive volume-averaged temperature of the studied fluid medium in the cylindrical vessel on the side of the water, °C

(2) $$\vartheta = \left| \overline{T_1} - \overline{T_2^{II}} \right|.$$

Excessive temperature is modulus of difference between volume-averaged temperature T_1 of the water (I-4) in the environment I and volume-averaged temperature T_2 of the body II:

(3) $$\overline{T_1} = \left(T_1^{I} + T_1^{II} + T_1^{III} + T_1^{IV} + T_1^{V} \right) / 5;$$

(4) $$T_2^{II} = \overline{T_2} \pm (0.01 \div 0.03).$$

Values 0.01-0.03 are obtained because of the calculation of the divergences between volume-averaged temperature of the studied fluid environment in the body II and volume – averaged temperature of the body II overall.
Volume-averaged temperature of the studied fluid medium in the cylinder $\overline{T_2}$:

(5) $$\overline{T_2} = \left(T_2^{I} + T_2^{II} + T_2^{III} + T_2^{IV} + T_2^{V} \right) / 5,$$

where $T'_1 \ldots T^{V}_1$ – are local temperatures, measured by thermocouples, installed in the thermal sensor 1 (1'-5') on the height in the external cylinder $I\text{-}_{ex}$ (Figure 1) with water I-4 (Figure 1); $T'_2 \ldots T^{V}_2$ – are local temperatures, measured by the thermocouples, installed in the thermal sensor 2 (1''-5'') in the cylinder $II\text{-}_{ex}$ (Figure 1) with the studied fluid medium II-2 (Figure 1).
Methods of mean integral values of temperatures $\overline{\overline{T}}_1$, $\overline{\overline{T}}_2$ determination, in the time range of $\tau_{i1} - \tau_{1\,(n+i)}$ are used by means of the dependences, presented in Table 3. It is taken into consideration that the time range takes new value $\tau_{i1} - \tau_{1\,(n+i)}$.

Values $\overline{\alpha}_1$ and $\overline{\psi}$ are obtained during processing of the experimental data in the following way. Specific thermal flux from the water I-4 to the body II is determined: $q_1 = q_2 = \frac{M_2 \cdot c_{p2} \cdot \overline{\overline{\Delta T}}_2}{F \cdot \Delta\tau}$, W/m², where M_2 – is the mass of the body II, kg; C_{p2} – is the averaged specific heat capacity of the body II, J/(kg·K); F – is the area of the external surface of the thin metal cylinder $II\text{-}_3$, m²; $\Delta\tau$ - is time interval, where studies are carried out, sec; difference of mean interval temperatures $\Delta\overline{\overline{T}}_2 = \overline{\overline{T}}_{21} - \overline{\overline{T}}_{2n}$ (see Table 3).

Table 3. Methods of mean-integral values of temperatures $\overline{\overline{T_1}}$, $\overline{\overline{T_2}}$ determination in the time range $\tau_1 - \tau_n$.

№	Studied fluid	Heat exchange direction	Dependence for the determination of temperatures in the environment, °C	Dependence for the determination of temperatures in the studied fluid medium, °C
1	sugar solution b=50%	heating	$\overline{\overline{T_1}}=\frac{\int_{\tau_1}^{\tau_n} 116.62\cdot x^{-0.073}d\tau}{\tau_1-\tau_n}$	$\overline{\overline{T_2}}=\frac{\int_{\tau_1}^{\tau_n} 13.573\cdot x^{0.2456}d\tau}{\tau_1-\tau_n}$
2	sugar solution b=50%	cooling	$\overline{\overline{T_1}}=\frac{\int_{\tau_1}^{\tau_n} 9.5206\cdot x^{0.1405}d\tau}{\tau_1-\tau_n}$	$\overline{\overline{T_2}}=\frac{\int_{\tau_1}^{\tau_n} 173.5\cdot x^{-0.284}d\tau}{\tau_1-\tau_n}$
3	sunflower oil	heating	$\overline{\overline{T_1}}=\frac{\int_{\tau_1}^{\tau_n} 99{,}919\cdot x^{-0.045}d\tau}{\tau_1-\tau_n}$	$\overline{\overline{T_2}}=\frac{\int_{\tau_1}^{\tau_n} 8.4629\cdot x^{0.323}d\tau}{\tau_1-\tau_n}$
4	sunflower oil	cooling	$\overline{\overline{T_1}}=\frac{\int_{\tau_1}^{\tau_n} 14.922\cdot x^{0.0691}d\tau}{\tau_1-\tau_n}$	$\overline{\overline{T_2}}=\frac{\int_{\tau_1}^{\tau_n} 250.21\cdot x^{-0.329}d\tau}{\tau_1-\tau_n}$

Heat transfer coefficient $\overline{\alpha_1}=\frac{\overline{Nu_1}\cdot\lambda_1}{H}$ is determined on the condition of free convection, applying the iteration method for the time intervals $\tau_1 - \tau_n$ and $\tau_1 - \tau_{(i+1)}$. For the determination of $\overline{Nu}_1$, the formula, recommended for the vertical surfaces (pipe) on the condition of the laminar mode ($10^3<(Ra_1)<10^9$) in the non-limited space [21] is used

(6) $$\overline{Nu_1} = 0{,}76Ra_1^{0,25}\left(\frac{Pr_1}{Pr_w}\right)^{0,25}$$

where $Ra_1 = Gr_1\cdot Pr_1$ – is Rayleigh criterion; $Gr_1 = (g\cdot\beta_1\cdot\overline{\overline{\Delta T}}\cdot H^3)/\nu_1^2$ – is Grashof criterion; g – is free fall acceleration, m/s^2; H – is characteristic length (distance on vertical from the surface of the metal bottom II-1 to the level of the studied fluid II-4 in the vessel), m; $\Delta\overline{\overline{T}} = \left|\overline{\overline{T}}_1 - \overline{T}_w\right|$ – is temperature drop; $\overline{T}_w$ – is external average temperature of the wall of the thin-metal cylinder II-3, washed by the water, °C; β_1 – is coefficient of thermal expansion of water, °C^{-1}; ν_1 – is the coefficient of kinematic viscosity of water, m^2/sec; Pr_1 – is Prandtl criterion – by mean-integral temperature of water within the limits of $\tau_1 - \tau_n$; Pr_w – is Prandtl criterion for the water of the temperature $\overline{T}_w$ of the wall in the process of iteration; λ_1 – is coefficient of heat conductivity of water, W/(m·K).

On the base of mean-integral value of water temperature $\overline{\overline{T}}_1$ (Table 3) within the time range of $\tau_1 - \tau_n$ thermal physical properties (TPP) of water are determined, namely, coefficient of thermal expansion β_1, kinematic viscosity υ_1, coefficient of heat conductivity λ_1.

Verification of the set external temperature of the wall II-3 in the time range of $\overline{T_w}=\overline{\overline{T}}_1-\frac{q_2}{\alpha_1}$ is performed. If the obtained temperature of the wall differs from the previously accepted by less than 3%, calculation is over and $\overline{\psi}$ is determined. Coefficient of the uneven temperature distribution in the system "E I – body II" is found from the dependence $\overline{\psi} = \vartheta_f/\vartheta_v$, where ϑ_v – is the excessive temperature of the body II relatively the temperature E I, $\vartheta_v = |\overline{\overline{T}}_1 - \overline{\overline{T}}_2|$, °C; ϑ_f – is the excessive temperature of the wall relatively the temperature $\overline{\overline{T}}_1$, $\vartheta_f = |\overline{\overline{T}}_1 - \overline{T_w}|$.

Results and discussion

According to Figure 4 and Table 4 dependence $\ln(\vartheta) = f(\tau)$ is of linear character, that proves the presence of regular thermal mode in the body II.

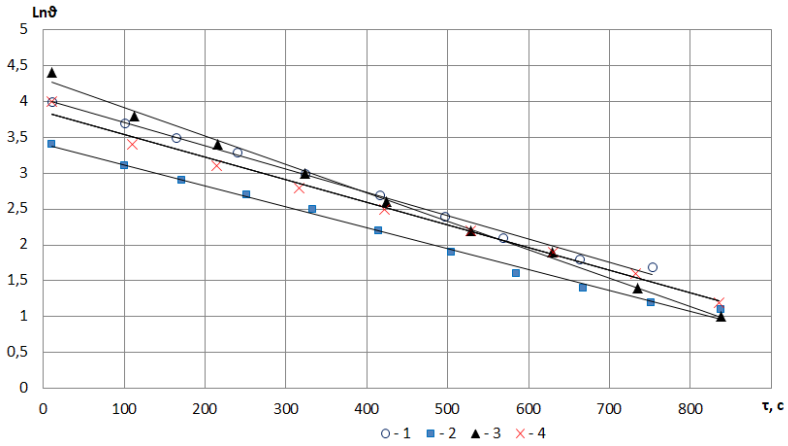


Figure 4. Distribution of the excessive temperature in time: 1 – sugar solution b=50% at heating; 2 – sugar solution b=50% at cooling; 3 – sunflower oil at heating; 4 – sunflower oil at cooling.

Table 4. Cooling (heating) rate of the studied fluid medium.

№	Studied fluid	Direction of heat exchange	Function of the form $\ln\vartheta=m\cdot\tau + C$	Determination factor R^2
1	sugar solution b=50%	heating	$\ln\vartheta = -0.0033\cdot\tau + 4.0355$	0.9931
2	sugar solution b=50%	cooling	$\ln\vartheta = -0.003\cdot\tau + 3.4342$	0.9964
3	sunflower oil	heating	$\ln\vartheta = -0.0038\cdot\tau + 4.2334$	0.9990
4	sunflower oil	cooling	$\ln\vartheta = -0.003\cdot\tau + 3.7605$	0.9989

Analytical substantiation of the validity of linear dependence $Ln\vartheta = f(\tau)$ regularity is presented [18]. In the given case differential heat-transfer equation in solid bodies on condition of the missing internal sources of heat is the output equation.

Experimentally obtained linear regularities $Ln\vartheta = f(\tau)$ for fluid environment, limited by thin-walled cylindrical envelope also can be explained, using differential thermal conductivity equation [18], if the notion of the equivalent thermal conductivity coefficient λ_{eq} and convection coefficient $\varepsilon_c = \lambda_{eq}/\lambda$, which characterizes the impact of convection is introduced. Convection coefficient characterizes impact of convection or condition of heat transfer from heat-releasing surface to heat-receiving surface throughout the fluid. According to [21] compound process of the convective heat exchange is considered as the elementary phenomenon of thermal conductivity.

In the solid bodies on condition of the regular thermal mode due to the temperature change λ does not change greatly. In our experiment λ_{eq} and ε_c also does not change greatly, within the limits of ±6%.

Figure 5 and Tables 5 – 10 contain experimental results for the comparison of the local in time heat transfer coefficients $\bar{\alpha}_1$ and local in time coefficients of uneven temperature distribution $\bar{\psi}$ for sugar solution b=50% and sunflower oil. Processing was performed, applying the method of stationary heat exchange, when the whole-time interval was studied, taking different steps Δ and changing time interval $\Delta\tau$; in the first case Δ=50 sec and $\Delta\tau$=100 sec; in the second case Δ = 90 sec and $\Delta\tau$ = 180 sec. Study of the experimental fluids is carried out in the identical temperature range.

The following designations of the local in time heat transfer coefficients are introduced:

- $\bar{\alpha}_{1(100)}$ – is local in time heat transfer coefficient between the water ($I\text{-}_4$) and external surface of thin-walled metal cylinder $II\text{-}_{ex}$ in the time range $[\tau_{i+1} - \tau_i]$ = 100 sec, W/(m²·K);
- $\bar{\alpha}_{1(180)}$ – is local in time heat transfer coefficient between the water ($I\text{-}_4$) and external surface of thin-walled metal cylinder $II\text{-}_{ex}$ in the time range $[\tau_{i+1} - \tau_i]$ = 180 sec, W/(m²·K).

The following designations of the local in time coefficients of uneven temperatures distribution in the body II are introduced:

- $\bar{\psi}_{(100)}$ – is local in time coefficient of uneven temperatures distribution in the body II in the time range $[\tau_{i+1} - \tau_i]$ = 100 sec;
- $\bar{\psi}_{(180)}$ – is local in time coefficient of uneven temperatures distribution in the body II in the time range $[\tau_{i+1} - \tau_i]$ = 180 sec.

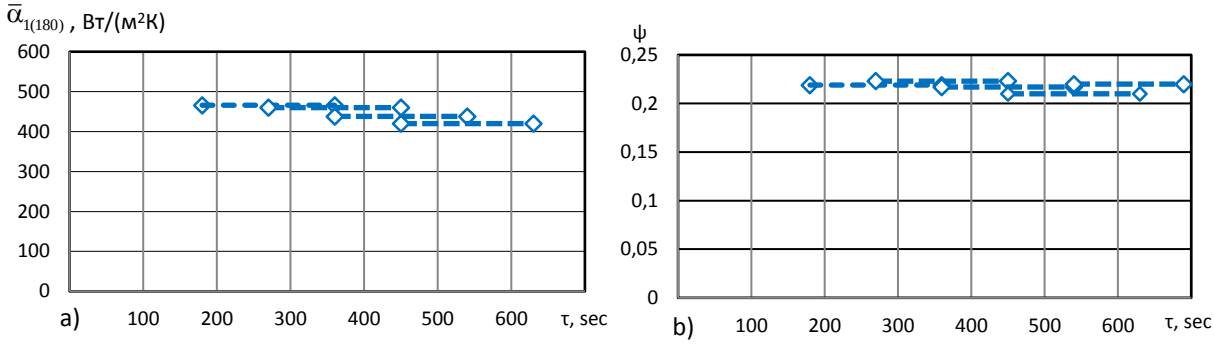


Figure 5. Heat transfer coefficients $\bar{\alpha}_{1(180)}$ between the water I-$_4$ and external surface of the thin-walled metal cylinder II-$_{ex}$ (a) and coefficients of uneven temperature distribution $\bar{\psi}_{(180)}$ in the body II in time while cooling sunflower oil.

In Tables 5 – 10 $\bar{\bar{T}}_{1TR}$ – is mean-integral temperature of water in the time range $[\tau_{i+1} - \tau_i]$ = 100 sec. or $[\tau_{i+1} - \tau_i]$ = 180 sec., °C; $\bar{\bar{T}}_{2TR}$ – is mean-integral temperature of the studied fluid medium in the time range $[\tau_{i+1} - \tau_i]$ = 100 sec. or $[\tau_{i+1} - \tau_i]$ = 180 sec, °C.

Table 5. Results of studying sugar solution b = 50% heating, $[\tau_{i+1} - \tau_i]$ = 100 sec.

№	Time interval Δτ, sec.	$\bar{\bar{T}}_{1TR}$, °C	$\bar{\bar{T}}_{2TR}$, °C	$\bar{T}_w$, °C	m, c^{-1}	q, kW/m²	$\bar{\psi}_{(100)}$	$\bar{\alpha}_{1(100)}$, W/(m²·K)
1	200-300	78.2	52.1	67.4		5.6	0.22	777
2	250-350	77	55	68		4.6	0.23	741
3	300-400	76.1	57.1	69.2		4.1	0.26	732
4	350-450	75.3	59.1	69.9	0.0032	3.7	0.27	700
5	400-500	74.7	60.8	69.8		3.4	0.28	676
6	450-550	74.1	62.4	69.8		3.2	0.29	645
7	500-600	73.6	63.9	70		3.0	0.31	618

Table 6. Results of studying sugar solution b = 50% heating, $[\tau_{i+1} - \tau_i]$ = 180 sec.

№	Time interval Δτ, sec.	$\bar{\bar{T}}_{1TR}$, °C	$\bar{\bar{T}}_{2TR}$, °C	$\bar{T}_w$, °C	m, c^{-1}	q, kW/m²	$\bar{\psi}_{(180)}$	$\bar{\alpha}_{1(180)}$, W/(m²·K)
1	100-270	76.1	53.2	69.2		4.8	0.26	804
2	180-360	75.4	57	69.9		3.8	0.27	746
3	270-450	74.9	60	69.8	0.0032	3.1	0.28	702
4	360-540	74.4	62.6	69.8		2.7	0.31	665
5	450-630	74.1	64.9	69.8		2.4	0.34	638

Table 7. Results of studying sunflower oil heating, $[\tau_{i+1} - \tau_i]$ = 100 sec.

№	Time interval Δτ, sec.	$\bar{\bar{T}}_{1TR}$, °C	$\bar{\bar{T}}_{2TR}$, °C	$\bar{T}_w$, °C	m, c^{-1}	q, kW/m²	$\bar{\psi}_{(100)}$	$\bar{\alpha}_{1(100)}$, W/(m²·K)
1	200-300	78.1	49.7	73.3		3.5	0.17	743
2	250-350	77.3	53.3	73.2		3.0	0.17	704
3	300-400	76.8	56.1	73.1		2.7	0.18	673
4	350-450	76.3	58.5	73		2.4	0.19	664
5	400-500	75.9	60.8	72.8	0.004	2.3	0.21	639
6	450-550	75.6	62.9	72.7		2.1	0.22	625
7	500-600	75.2	64.9	72.5		2.0	0.23	604
8	550-650	74.9	66.8	72.5		1.9	0.23	579

Table 8. Results of studying sunflower oil heating, $[\tau_{i+1} - \tau_i]$ = 180 sec.

№	Time interval Δτ, sec.	$\overline{\overline{T}}_{1TR}$, °C	$\overline{\overline{T}}_{2TR}$, °C	$\overline{T_w}$, °C	m, c^{-1}	q, kW/m²	$\overline{\psi}_{(180)}$	$\overline{\alpha_1}_{(180)}$, W/(m²·K)
1	100-270	77.4	51.6	73.7	0.004	2.7	0.18	730
2	180-360	76.6	56	73.6		2.2	0.18	678
3	270-450	76.1	59.5	73.6		1.8	0.20	663
4	360-540	75.6	62.5	73.4		1.6	0.22	625
5	450-630	75.3	65.1	73.4		1.4	0.19	545

Table 9. Results of studying sugar solution b = 50% cooling, $[\tau_{i+1} - \tau_i]$ = 180 sec.

№	Time interval Δτ, sec.	$\overline{\overline{T}}_{1TR}$, °C	$\overline{\overline{T}}_{2TR}$, °C	$\overline{T_w}$, °C	m, c^{-1}	q, kW/m²	$\overline{\psi}_{(180)}$	$\overline{\alpha_1}_{(180)}$, W/(m²·K)
1	100-270	20.2	38.2	27.6	0.0029	4.5	0.41	654
2	180-360	21.1	34.7	26.4		2.7	0.39	567
3	270-450	21.8	32.6	25.8		2.0	0.37	508
4	360-540	22.2	31.1	25.8		1.5	0.4	484
5	450-630	22.7	30	25.8		1.2	0.42	453
6	540-720	23	29,1	25.7		0.9	0.44	420

Table 10. Results of studying sunflower oil cooling, $[\tau_{i+1} - \tau_i]$ = 180 sec.

№	Time interval Δτ, sec.	$\overline{\overline{T}}_{1TR}$, °C	$\overline{\overline{T}}_{2TR}$, °C	$\overline{T_w}$, °C	m, c^{-1}	q, kW/m²	$\overline{\psi}_{(180)}$	$\overline{\alpha_1}_{(180)}$, W/(m²·K)
1	100-270	21.4	40.9	25.2	0.0032	2.5	0.19	507
2	180-360	22	37.2	25.2		1.5	0.21	486
3	270-450	22.3	35	25.1		1.0	0.22	466
4	360-540	22.6	33.4	25.3		0.8	0.22	460
5	450-630	22.8	32.2	24.9		0.6	0.22	438
6	540-720	23	31.2	24.8		0.5	0.22	420

It was established experimentally, that the features of the RTM take place in the studied system, i.e., heating rate of the studied fluid in the cylinder vessel m=const; heat transfer coefficient is practically stable in the process of RTM $\bar{\alpha}_1$=const; coefficient of uneven temperatures distribution $\bar{\psi}$=const. Characteristic features of the RTM are presented in Table 11.

The existence of dependencies of ψ=const and α_1=const for solid bodies can be expended as a result of the realization of linear dependence Lnϑ=f(τ), i.e., m=const [15,21]. The same substantiation of ψ=const and α_1=const can be made for the volume of the fluid in thin-walled metal cylinder envelope, if it is taken into account that the compound process of heat exchange is considered as the elementary phenomenon of thermal conductivity [21].

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In the body II, components of which are fluid and metal on conditions of cooling (heating) RTM, characteristic for solid bodies, set of solid bodies, is realized.

Based on experimental studies, presented and analyzed above, for the fluid in thin-walled metal cylindrical envelope, for the whole range of the regular thermal mode of cooling (heating) it is established that ψ = const, α_1 = const, m = const.

Table 11. Characteristic features of the RTM.

Studies of G.M. Kondratiev [15]	**Authors studies**
1. Features of the regular thermal mode	
Body	Body II
1.1. Cooling (heating) rate of the body - m	
m = const	m = const
1.2. Heat transfer coefficient on the boundary E – body	
Remains stable α_1 = const	Slightly changes $\alpha_1 \approx$ const; $\frac{\overline{\alpha_1}-\alpha_{1m}}{\alpha_{1m}}\cdot 100\% = \pm 13\ldots 16\%$ - heating; α_{1m}- arithmetic mean value $\frac{\overline{\alpha_1}-\alpha_{1m}}{\alpha_{1m}}\cdot 100\% = \pm 14\ldots 25\%$ - cooling.
1.3. Coefficient of non-uneven temperatures distribution in the body ψ	
Remains stable ψ = const	Slightly changes $\psi \approx$ const; $\frac{\overline{\psi}-\psi_m}{\psi_m}\cdot 100\% = \pm 10\ldots 17\%$ - heating; ψ_m - arithmetic mean value $\frac{\overline{\psi}-\psi_m}{\psi_m}\cdot 100\% = \pm 10\ldots 18\%$- cooling.
2. Temperature of the environment in the process of cooling (heating)	
Remains stable $\overline{T}_1$=const	Changes by 3…6°C, $\overline{T}_1 \neq$ const

Heat transfer coefficient $\overline{\alpha_2}$ between the internal surface of the thin-walled metal cylinder II – 3 and studied by RTM method fluid environment (Figure 1) is determined by the expression

$$\overline{\alpha_2} = \left(\frac{F \cdot \overline{\Delta T}}{Q} - \frac{F \cdot \overline{\psi}}{m \cdot C_1} \right)^{-1} \quad (7)$$

where Q – is heat flux, taken by the studied fluid environment locally in time, W; $\overline{\Delta T}$ – is mean overall temperature drop, °C; F – is the area of the thin-walled metal cylinder, m^2 ; C_1 – is specific heat capacity of the environment (water), J/(kg·K); $\frac{F \cdot \overline{\psi}}{m \cdot C_1}$ – is thermal resistance of the heat exchange between the environment (water) and wall [15], $(m^2 \cdot K)/W$.

Heat transfer coefficient $\overline{\alpha_2}$ also can be determined by the known dependence

$$\overline{\alpha_2'} = \left(R_{ov} - R_1 - R_w \right)^{-1}, \quad (8)$$

where R_{ov} – is thermal resistance of the heat exchange between the environment (water) and studied fluid environment, $(m^2 \cdot K)/W$; R_1 – is thermal resistance of environment (water) and thin metal wall, $(m^2 \cdot K)/W$; $R_w = \delta_w/\lambda_w$ – is thermal resistance of thermal conductivity across thin metal wall is 1 % of the total and in the given case is not taken into account, $(m^2 \cdot K)/W$; δ_w – is the thickness of the wall of the thin metal cylinder, m; λ_w – is thermal conductivity of the wall of the thin metal cylinder, W/(m·K).

Heat transfer coefficient $\overline{\alpha_2''}$ can be determined applying the known criterial equation for large volume [16,17]. Difference between $\overline{\alpha_2}$ and $\overline{\alpha_2'}$ is up to 10 %. Difference between $\overline{\alpha_2}$ and $\overline{\alpha_2''}$ is up to 40 % [22]. That is why, determination of $\overline{\alpha_2}$, applying criterial dependences for large volume does not enable to predict the intensity

of heat exchange with the sufficient accuracy. Thus, the method of regular thermal mode allows to describe the regularities of heat exchange between the fluid environment and metal cylindrical wall in the vessel of limited dimensions. Thus, experimentally calculation method of the heat exchange intensity prediction in compound fluid mixtures has been improved.

Impact

Biogas – it is a gas, obtained by means of hydrogen or methane fermentation of the biomass. Biogas units are used for obtaining biofuel of the first generation. Their advantage is the possibility of useful disposal of the organic waste of the cattle breeding, crop growing, domestic waste, sewage water, etc., with positive energy, ecological, social and economic effect [3,23,24].

Performance and material-output ratio of the biogas unit and correspondently investments in its construction greatly depend on the efficiency of thermal technological processes in the bioreactor.

To provide high efficiency of biogas technologies at modern scientific level it is necessary to coordinate thermal technological and biotechnological processes. Nowadays for the solution of this problem the study of the regularities of heat and mass exchange in the compound fluid environments used in biogas units is not sufficient nowadays [3,10,24,25].

Authors suggested experimentally-calculation method for the forecast of the intensity of heat exchange intensity in the compound fluid environments with limited information regarding thermal physical properties [9,10,14]. This method enables to determine more accurately the needed area of the surfaces of heat exchange equipment of biogas units, and this will reduce specific amount of metal per structure.

ECM provides for large amount of the experiments with the compound fluid environments and «auxiliary fluids» with known thermal physical properties and rheological behavior at the basic experimental bench [12,13]. In the given research the existence of regular thermal mode in fluid environment in the thin metal cylindrical envelope was determined experimentally. The advantage of RTM as the method of studying heat exchange intensity is the simple technique of experiments, high accuracy of the obtained results and low time consumption for carrying out the experiment. All these characteristics improve experimental-calculation method.

Therefore, the suggested methods enable to reduce metal consumption of biogas units, investments in their construction and technogenic pressure on the environment during the life cycle at the expense of more accurate determination of heat-exchange intensity in the compound fluid environments.

Conclusions

Problem of heat exchange forecast in the compound fluid environments with limited data regarding TPP and rheological behavior in real technological processes exists in theoretical and applied aspects.

It was established experimentally, that in the studied system «environment I – fluid environment in thin metal cylinder envelope (body II) the features at regular thermal mode take place i.e., heating (cooling) rate of the studied fluid in the cylinder vessel m=const; heat transfer coefficient is practically stable $\overline{\alpha_1}$ =const; non- uniformity factor of temperatures distribution $\bar{\psi}$=const. Studies have been carried out for c=50% sugar solution end sunflower oil.

Thus, the method of regular thermal mode allows with a reasonable degree of accuracy to describe the regularities of heat exchange between the fluid environment and metal cylindrical wall in the vessel of limited dimensions.

ECM is improved because of more profound study of heat exchange regularities by means of experimental methods, in “auxiliary fluids” with the known TPP and rheological behavior at the basic experimental bench.

The obtained scientific result is the base for further study of ECM, aimed at the forecast of heat exchange intensity in thermal technological equipment of biogas technologies.

Conflict of interest

There are no conflicts to declare.

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RECENT INNOVATIONS IN SOLAR ENERGY EDUCATION AND RESEARCH TOWARDS SUSTAINABLE ENERGY DEVELOPMENT

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Highlight
This review focuses on recent developments in solar energy-based research and education and future trends toward sustainable energy development.

Abstract
The essential requirements of our everyday lives are fresh air, pure water, nourishing food, and clean energy in a most sustainable manner. The present review article concisely discusses recent innovations in solar energy education, research, and development toward providing clean and affordable energy and clean water to some extent. This article primarily addresses the Sustainable Development Goal 7 of the United Nations (SDG 7: Affordable and Clean Energy). Over the past few decades, many research activities have been carried out on solar energy conversion and utilization. The deployment of solar energy technologies has been witnessed to combat global warming and the betterment of the planet. Drivers and barriers to implementing solar energy systems from school to master's level through real-time deployments are discussed for further development and innovations. Mainly, expedited solar energy education and research are essential to improve solar energy utilization. The advancements in solar energy education and research towards sustainable energy development and circular economy are highlighted along with further directions required.

Keywords
solar energy; energy education; climate change; research and development; innovations; sustainable development.

Introduction
The environmental impact of fossil fuel burning has been particularly damaging to human, plant, and animal life. It is commendable that the momentum for conserving the rapidly decreasing available fuels and the utilization of renewable energy is on solid footing. Countries are asked to develop ambitious 2030 emission reduction targets to reach net-zero by the middle of the century at the United Nations Climate Change Conference held in London in November 2021 [1]. At this conference, securing global net-zero by mid-century and keeping 1.5 degrees within reach has been primarily targeted. The current pace must be expedited with maximizing renewable energy utilization to reach such a target. SDG 7 deals mainly with affordable and clean energy to combat climate change. Every citizen must be sensitized to the necessity of protecting our environment, sustaining the fast-depleting natural resource, maximizing the energy potential of clean energy sources, and preserving the natural wealth of the planet to be bequeathed to future generations. Implementation of proper energy education and practical research activities can foster advanced energy conversion technologies. The awareness of harnessing clean energy sources for the continued sustainability of the planet is vital and needs to be acted upon promptly. Solar energy is an option that should be given prime importance.
Solar energy from the Sun is unlimited, and this abundant energy can be utilized by us effectively. It is essential to assess the energy needs and apply the required techno-economical skills to ensure that solar energy is tapped and utilized to our energy needs. Solar energy education is essential to achieve energy awareness and energy sustainability [2,3]. Unbridled human activities have resulted in the extinction of several species all over the world. Before it is too late, precautionary measures must be taken to protect the planet and ensure that it is habitable for generations to come. Therefore, sustainability is at the forefront of all developmental activities. In his context, the present review article focuses on solar energy education and research with the recent advancements.

Directly and indirectly, 70% of emissions were from households in Netherlands and Spain. Education and structural factors were significant for climate mitigation on the demand side [3]. Job creation is increasing with solar and wind energy deployments. Solar photovoltaic (PV) installations and maintenance are potential areas of job creation across the globe up to 2050 [4]. New renewable energy programs were required to promote Saudi Arabia's renewable energy utilization goals by 2030 [5]. Various education and research activities are necessitated to provide skilled people for wind and solar power deployments and maintenance [6]. Learning-by-doing and research activities were important drivers of impact reduction cost in energy technologies [7]. Energy management in households by insulating houses and implementing measures for solar energy utilization were the driving factors of sustainability [8–10]. Solar PV systems were projected as potential to meet sustainability goals [11–13]. Carbon pricing and low carbon technologies, such as solar technologies, are potential aspects of energy sustainability [14–17].

A survey among school students and teachers exposed energy savings, solar energy, and biomass technologies [18]. Inculcating renewable energy practices in school curricula is required to promote renewable energy sources (RES) and maintain the green campus. Lack of energy policies, financial assistance, and subscription issues was observed as barriers in promoting solar communities [19]. The driving factors were energy sustainability and grid resilience. Building energy management practices are essential to promote clean energy and energy-saving practices [20]. A laboratory-scale solar microgrid system with wireless data monitoring was introduced as a teaching tool in the engineering technology curriculum [21]. It was found that the students learned solar deployment and integration issues through real-time experiments. Off-grid home electrification was promoted, and the importance of all stakeholders was stressed in the deployment and maintenance of photovoltaic systems [22].

Although novel and highly efficient solar cell materials have been demonstrated on a laboratory scale, the availability of such materials, such as gallium, indium, arsenic, bismuth, and selenium, is unsustainable on larger scales [23]. In the terawatt solar PV deployment path, multijunction solar cells were observed as not sustainable till 2030. Material synthesis aspects are to be concentrated to meet 2050 solar PV deployment targets. Material innovations are essential with the roadmap to sustainability and reliability in the long-term energy market. Large-scale batteries and solar-operated battery vehicles were critical requirements for successfully deploying solar PV installations [24,25]. In addition to energy, water and food are the other SDGs that solar energy technologies should partly support. Several researchers have investigated solar desalination technologies to provide potable water [26,27]. Goel et al. [28] indicated that around 85% of the population is expected to live in developing countries by 2030. A smart agriculture concept was essential for food security by interconnecting agriculture, information systems, and energy systems. Bioinspired solar cells are evolving in research to imitate nature to convert solar rays into useful energy. Currently, ongoing research synthesizes organic materials for such bioinspired energy conversion and storage [29].

Various initiatives have been formulated to educate and encourage renewable energy education to provide fundamental knowledge and hands-on experience in a real-time scenario to promote more innovations and patents, especially in solar PV technologies. The institutional innovative teaching methodologies could be closely associated with people to realize the benefits of renewable energy utilization and protection of environmental concerns. Bridging the gap between academic institutions and industries is a critical factor in reaching out to the community in large-scale solar PV installations and steady progress to combat climate change.

Even though several studies on solar energy research are available, a specific focus on innovations in learning and product developments is demanding. This short review provides deep insights into teaching and learning requirements for various solar applications, ranging from solar thermal to electrical systems. Further, the current research and future directions are essential to solar professionals. This review discussed solar utilization in different sections. The introduction section contains the present study’s needs and objectives. The following methods section are mainly dealing with recent developments in solar energy education and research. The discussion section deals with the pros and cons of the study. The impact section narrates how the present study impacts the solar community. Finally, concluding remarks and future scopes are provided in the conclusions section.

Methods

Solar energy utilization is one of the fastest-growing and cost-competitive renewable energy sources worldwide.

The solar energy-based research and education trends are observed using the widely used Scopus database [30] (www.scopus.com). It was assessed on November 12, 2021, based on the search keyword 'solar energy'. The total documents are 1,85,335, including articles, conference articles, review articles, book chapters, conference review articles, and others, as per Figure 1. This section discusses mainly solar and associated other RES that have been promoted in the last decade. Figure 2 shows Scopus-indexed publications based on solar energy research, education, solar energy utilization, and energy conversion. A significant increase in the number of Scopus-indexed publications of articles on all the areas of solar energy and sustainable education has been witnessed in the last decade due to the various global environmental legislations.

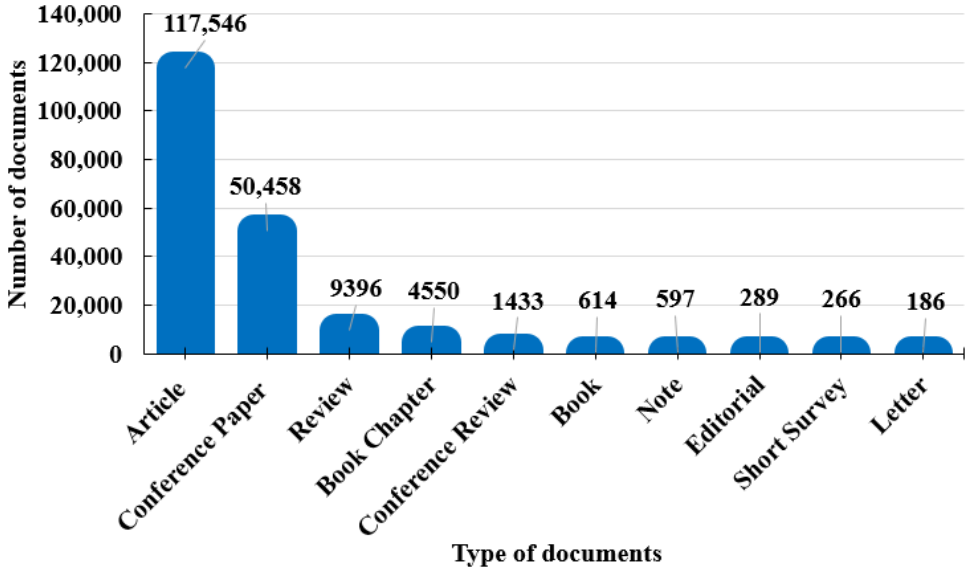

Figure 1. The types of selected documents as per the search keyword "solar energy" on Scopus database 2011 to date (Assessed on 12th November 2021).

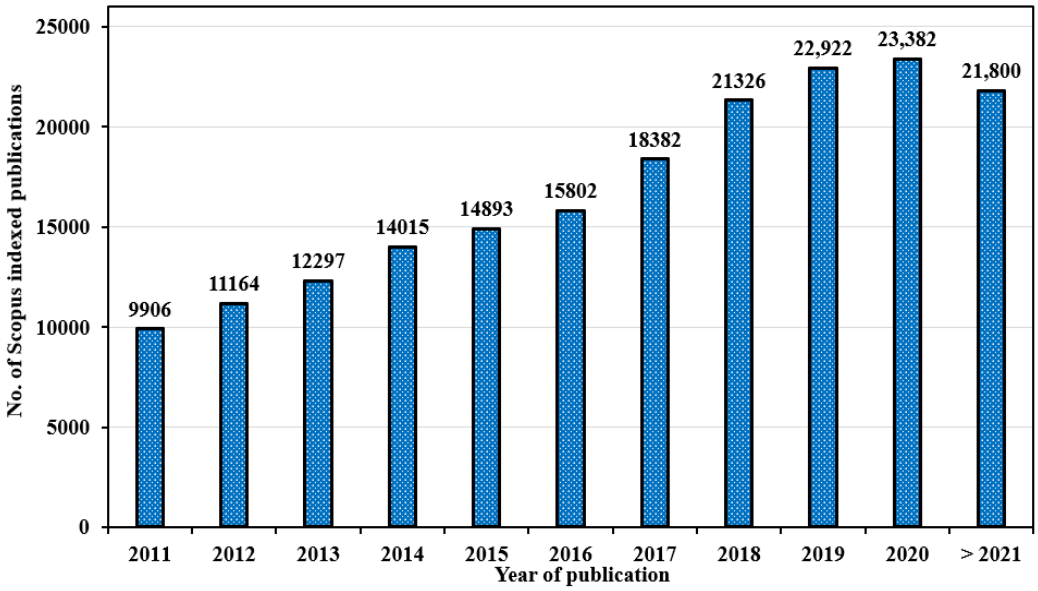

Figure 2. The total number of documents published on solar energy during the recent decade is per the Scopus database.

It has been observed; the article publication statistics have increased gradually; however, from 2017, escalating publications have been observed. This implies that solar energy utilization increased at its best with adequate energy education and related research works in the last three years. Figure 3 illustrates the top ten nations that are excelling in solar-based research publications. China (22%), the United States (18%), and India (11%) were

produced almost half of the total documents published in the last decade. In this category, India and Germany were listed in the third and fourth positions, respectively. Almost every country receiving significant solar rays contributes more technologies to society; however, the leading countries are listed here.

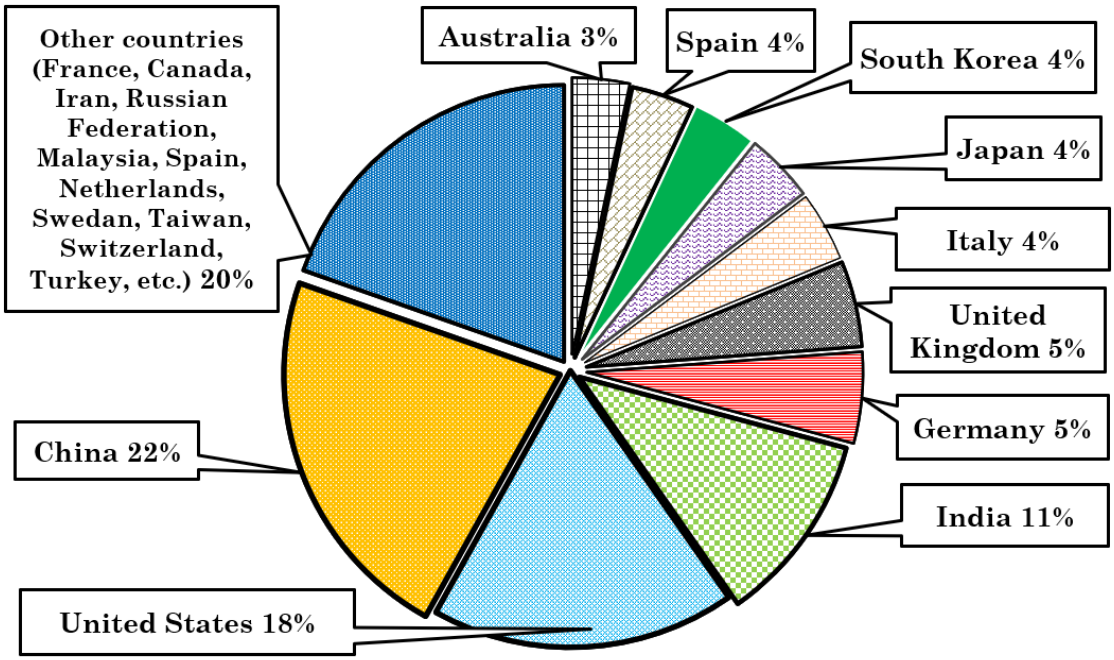

Figure 3. The percentage contribution of leading countries on solar energy research and education. *Source: Scopus indexed publications (2011-2021).*

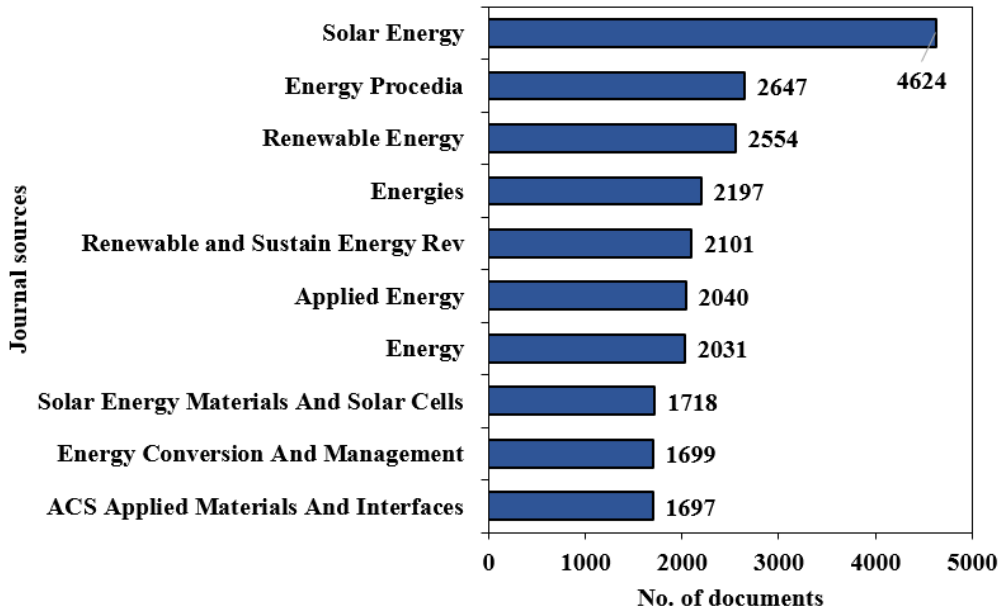

Figure 4. The number of documents published by top ten source titles on solar energy. *Source: Scopus indexed publications (2011-2021).*

The discussion of recently published articles is carried out to give more insight into the prospects of solar energy technologies towards sustainable development. The primary research area in solar energy is solar cell technologies due to their direct conversion of solar rays into electricity. The published articles in the solar cell-based research area are nearly 60% and solar thermal-based research has a share of 40% of the total publications.

In the recent three years, solar cell development has been around 70% of research output in publications. Thus, the statistics of Scopus indexed publications witness the recent development in the solar energy education and utilization aspects. Almost all the top energy journals contribute significantly and promote solar energy research. The various familiar keywords in solar energy are denoted in Figure 5 Solar power generation is the dominant aspect of the use of solar photovoltaics and cells. Although the solar energy market is growing exponentially, several researchers have also sought new solar cell technologies worldwide.

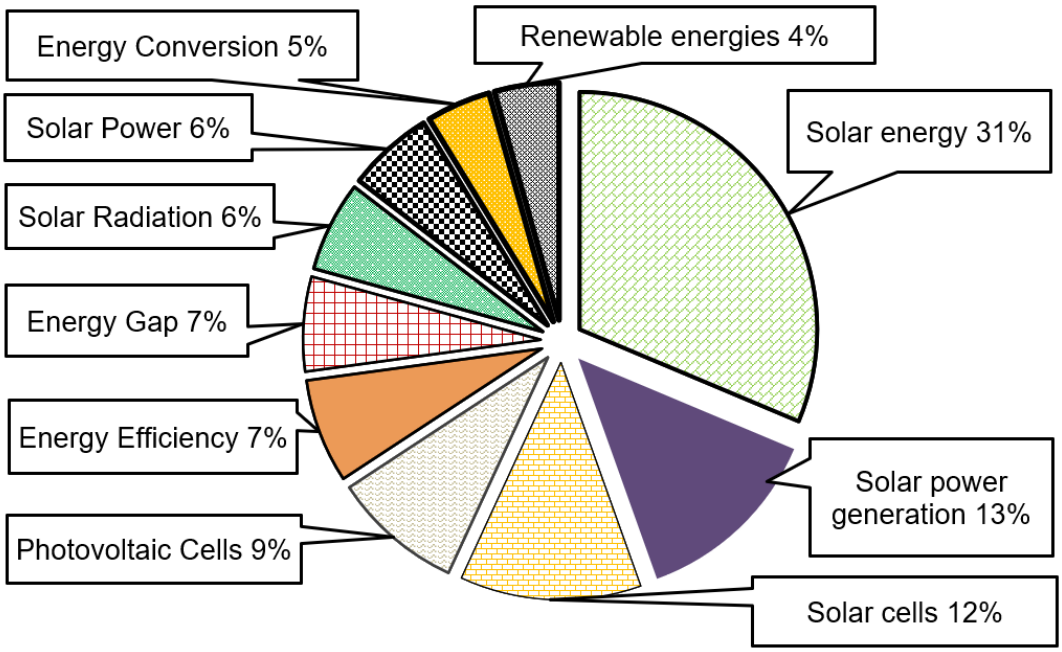

Figure 5. The top ten keywords used by researchers on solar energy. *Source: Scopus indexed publications (2011-2021).*

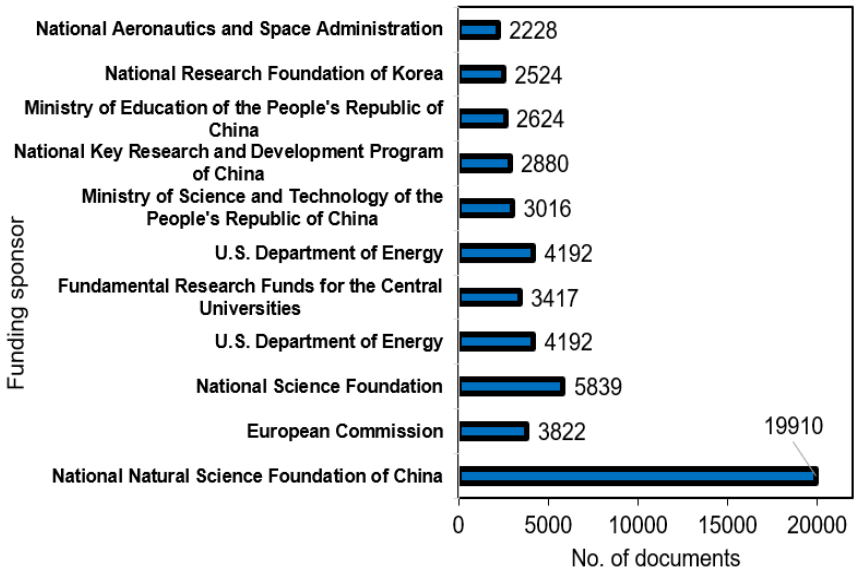

Figure 6. Top ten funding sponsors in solar energy in recent years.

The main findings are that cell efficiency and reliability under the varying solar intensity are investigated for real-time deployments. The leading sponsor in solar energy is shown in Figure 6. The total number of documents published by the sponsors is also shown to understand solar energy researchers better. The funding is an essential aspect to attain carbon-free environments with the help of energy efficiency measures and renewable energy adaptations.

Literature on Solar Energy Education.

Renewable energy-related classes, discussions, applied projects, demonstrations, industry interaction, collaborations, laboratory experiments, and programs in higher education institutions (HEI) play an essential role in preparing students for a career in energy-related science, technology, engineering, and mathematics (STEM) fields. Recent innovations in teaching and learning and sustainability are discussed.

- Learning through real-time projects.

A university-level research study was conducted through questionnaire mode on teaching effectiveness and implementation of renewable energy education in Turkey [31]. Only the usual core courses were taught at undergraduate levels. The renewable energy courses were mainly taught only at the master's level. There was an apparent lack of experts in the field of renewable energy and education. The Solar Info Center in Freiburg, Germany, was established to offer many services in renewable energy and energy efficiency [32]. The building features a rational, sustainable, and ecological energy and technology concept. Germany's first energy-certified office building to be 100% emission-free heated with a low energy demand for heating of 26 kWh/m^2. Pasqualetti and Haag discussed the steps considered for meaningful development in solar energy harvesting in the American Southwest [33].

The design, construction and testing of a small solar-powered boat for tourism, with senior class engineering students taking hydrodynamic, energy and economic factors, were discussed by Rivera-Solorio [34]. Students used specialized engineering software tools to explore innovative ideas and new concepts, enhancing their creativity in the context of developing a successful prototype to compete in a solar splash event. The solar energy industry needs professional competence (scientific and technological knowledge) to develop a related engineering education curriculum for green energy [35].

Educational competition influences educational outcomes, and inclusive education is one of the successful measures to meet students' technical and professional ambitions [36]. Most of the students recognized that their knowledge and skills increased with improved experiential learning; they gained valuable conceptual insights and an understanding of technical and multidisciplinary aspects while working on real-time renewable energy projects. Employability indicators were established to capture solar energy enterprises' professional competency requirements and performance standards [37]. The indicators can serve as a basic framework for understanding the critical need for green energy to develop a sound knowledge base. The engineering curriculum covers fundamental concepts and processes to equip students with the necessary skills to design renewable energy systems. Professional knowledge, technical competence, efficient job performance, positive working attitude, career readiness, and perceived employability were essential factors that had a bearing on recruitment and employment by the solar industry.

There continues to be accelerated technological progress in the renewable energy field. Greater dissemination of knowledge of different forms of green energy and public awareness of RES could help popularize the same [38]. The noted factors such as gender, age, education level of family members, and eco-friendly behavior due to occupation influence greater social acceptance of new technologies, change attitudes towards renewable energy initiatives and increase environmental consciousness. The impact of contemporary technology classes, a new online learning platform, video-based e-learning of solar photovoltaic concepts [39] was investigated. The short interactive and informative videos facilitated 'learning by seeing'. They were broadcast through a popular online video channel containing more images, graphics, animations, and less textual content. Feedback obtained from students revealed that the e-learning was informative and educative and supported effective learning of important theoretical concepts. The various dimensions of the e-learning process were explored for gaining knowledge about breakthroughs in energy technologies [40]. Thus, the students explored various aspects of deploying new energy technologies, learning much about the practical aspects such as installation cost, utility-scale renewable energy.

There was a strong correlation between the integration of the study and the associated applications to make solar energy affordable for the masses [41]. Renewable energy applications must be given importance during the minor and major research or design projects and professional curriculum development and dissemination to offer creative technology education to the upcoming generation.

Technical innovation has resulted in intelligent grid systems, prompting to upgrade of the energy engineering curriculum in Jordanian universities to provide more excellent technical knowledge and a better understanding of such systems. Furthermore, equipping engineering students with the required workplace skills in terms of solar and wind power technologies improves employability in the energy sectors [42]. State-of-art laboratories

were set up in a bid to offer a comprehensive degree program on smart grids. Identifying the local aspects of the technological learning process for the deployment of new renewable energy technologies was discussed [43]. The local context is essential as technology is deployed regionally using locally available energy resources, local governance, and local talent in selecting, designing, fabricating, installing, and operating energy systems. The study focused on the empirical evidence of learning processes in PV deployment. The implications of government policy must acknowledge the importance of local aspects of technological learning for deploying new energy technologies. The working of solar photovoltaic systems and the maximum power point tracking role in improving power output were taught using soft tools [44].

Time- and incentive-based power demand response programs were utilized to meet the high load demand. Its applicability to current smart grids to ensure better power quality and reliable energy supply at competitive rates through a user-friendly two-way digital communication between the consumer and the utility provider using smart metering systems [45]. The implementation of smart grid technology has linked suppliers and consumers, making it possible to reduce energy consumption, minimize power losses, outages and avoid hefty payments for high load demand. The combined power and drinking water production using inclined PV panel integrated solar stills were investigated by Manokar et al. [46]. The parameters studied were fresh drinking water produced, still efficiency, PV panel power production, PV panel efficiency, and exergy efficiency. Sensing the need for renewable energy education, a fully functioning solar photovoltaic laboratory model was used to demonstrate and teach engineering students the components of the system, the working principles, and the maximum power point to improve their understanding of the theoretical course on RES [47]. The experiments were designed to be used along with the theoretical renewable energy course. The results of the hands-on experiments could be viewed in animation form.

- Multidisciplinary approach.

The importance of the multidisciplinary aspects of the Master's program in solar energy was insisted, and the required knowledge includes science, engineering, economics and management disciplines for the successful implementation [2]. The efficient and cost-effective solar systems are the need of the hour to change the perspectives of society. The introduction of laboratory-based courses on sustainable energy as part of the core curriculum was done for students who pursue non-STEM degree choices to create general awareness of the impact of climate change and the importance of clean energy throughout the student community [48]. The courses included hands-on exercises that provided an overview of renewable energy by demonstrating the basic principles. Students must know that the need for affordable, reliable, efficient, clean, and sustainable energy is universal, and it is central to a country’s economic growth and development. Knowledge of the main principles of different energy sources, sustainable energy systems and improved energy efficiency measures is necessary to meet the clean energy goals of the future.
With growing interest in alternative energy sources, there is an urgent need to design a well-structured multidisciplinary undergraduate course on alternative energy engineering [49]. A multidisciplinary undergraduate alternative energy engineering (AEE) course is required to bridge the existing gaps in AEE education and social needs and to educate a growing workforce about the need for a future supported by clean energy. The renewable and alternate energy courses were compiled by considering industry needs, potential opportunities, economics and policies of AEE. In addition to covering the principles, practices, and prescribed standards, this educational course addressed the integration of energy sources for effective renewable power generation and utilization. Both the undergraduate and postgraduate levels of study in sustainability engineering were presented by Thürer et al. [50]. Knowledge dissemination will enhance the competencies of students to promote renewable energy vigorously and aggressively.

Brazil's public schools invested large amounts of money in guaranteeing electricity through solar photovoltaic installations, as Brazil enjoys plentiful sunlight [51]. By scaling up solar power systems, a successful roadmap to sustainability was laid by the selected 15 schools. The full electrical demand of all the selected schools was effectively met by power generated from PV plants. There was a significant saving of the amount expended earlier on electricity bills on achieving energy self-sufficiency, which was fruitfully invested in educational programs and extracurricular activities. The residents’ response to renewable power subsidies offered by the government was investigated to promote renewable energy while also addressing the problem of high-cost installations [52]. The significant factors influencing the reactions and expectations of people were income, level of education, and employment fields. Table 1 shows various initiatives and measures are practiced in educational programs to promote solar energy deployments.

Table 1. Various educational initiatives and measures.

Reference	Innovative practices	Activities related to learning and promotion of solar technologies
[53]	Solar energy adoption	Integration of institutions to promote solar energy adoptions
[54]	Solar turtle	Providing mobile solar power to no power-grid areas
[55–57]	Consumer's adoption	Improving consumer intentions to adopt solar innovations
[58]	The road to net-zero	Innovations and policy changes to develop a net-zero pathway thought organizations and institutions
[59]	MySuria	Identification of economically weaker people and promoting solar PV, and improving their incomes by providing necessary education
[60]	Organizational life cycle assessment	Providing innovative solutions to solar and wind projects
[61–63]	Energy security in smart cities	Necessitates better management and vital networking of leaders to drive smart city policies and investments
[64]	Inter-sectoral learning	Envisaging the inter-sectoral learning on different renewable energy technologies
[65]	Load-demand pull policy	Promoting solar PV innovations and patents
[66]	Sustainability perspective	Sustainability tool is proposed as an essential aspect to promote solar PV technologies
[67–70]	Biomimetic engineering	Promoting the learning of solar energy technologies by biomimetic engineering cases
[71–74]	Virtual laboratory	Visualization of solar energy systems and their performance in real-time

Literature on Solar energy research

The effect of solar energy research on sustainability is discussed here. The critical policy implications for long-term energy planning in developing countries such as China and India were presented[75]. Between 2009 and 2020, he predicted the rapid development of biomass and wind power and the relatively stable solar power growth.

- Solar cell technologies

A case study on public perceptions of energy efficiency about paying for renewable energy utilized for domestic needs was conducted. A questionnaire method was adopted to interact with residents to obtain their opinion for the study conducted in Greece [76]. The study's findings revealed that the respondents were open to the idea of renewable energy systems; they had reasonably good knowledge of solar and wind energy systems and awareness of the need for environmental protection. The respondents were ready to pay for the switch to green renewable energy systems like solar water heaters and PV power installations. Education, energy subsidy, and government policies are the major factors associated with the willingness of the respondents to utilize solar energy systems.

Smart windows with active dynamic glazing technologies were installed to reduce heat loss, control solar radiation, and improve thermal and visual comfort of buildings [77]. Smart windows were electrochromic, halochromic, and nanocrystal in-glass composites, electrokinetic pixels, and liquid-filled elastomer-deformation windows. The importance of organic solar cells through photon-electron interactions in molecular systems and crystal lattices was discussed [78]. A light-intensity-wavelength diagram was used to discover the photons absorbed dyes. The necessity of framing ethical rules and stringent regulations was discussed to procure conflict minerals, critical minerals, and rare earth elements for alternative energy research in HEI and research laboratories [79]. The importance of using responsibly procured and ethically sourced minerals and metals fully complying with established laws and procurement guidelines was stressed.

Dye-sensitized solar cells (DSSCs) have garnered widespread scientific and technological interest. A scientific teaching module was formulated to support the continued growth of technological innovation in renewable energy and foster learning through inquiry by enabling high school students to fabricate using a simple process using natural dyes to make their own DSSC. The conversion of solar energy to electrical energy is demonstrated to power small household electrical appliances used in everyday life using sunlight to produce the energy needed to drive a small fan motor; more than 80% of high school and middle school students successfully constructed

a DSSC in 2.5 hours [80]. The process also gave them a better understanding of the working principles of solar cells, solar energy utilization, and the importance of alternative sources of sustainable green energy. Such practical application modules will help foster good conceptual understanding, spark interest, and encourage lifelong learning to improve the quality and speed up engineering education and research.

Luminescent solar concentrator (LSC) is a newly emerging, promising technology because it allows a large collecting area of virtually transparent glass with a comparatively small area of expensive solar cells. It is being investigated as a low-cost method to expand the use of solar energy. Painting with a technical activity aims to promote greater creativity in LSC construction and engage students in adopting renewable energy [81]. Students first painted luminescent dyes on plastic waveguides. Students were encouraged to show off their artistry on devices that could produce energy. The process was beneficial in improving students' creativity in STEM through the painting and testing of LSC materials at the laboratory, motivating students to harvest the freely and abundantly available solar energy. The popularity of a residential solar water heater offers both economic and environmental advantages were studied [82]. They discussed the economics of the usage of solar water heaters in Turkish households.
The adoption of solar water heaters largely depended on factors like income, education, geographical location, type of space heating system, and the whether the residents were owners or tenants. The percentage of households using polluting solid fuels for heating was determined as 61%. The installation of solar water heaters reduced energy consumption by 13%. The solar water heater installation in the owner and tenant-occupied homes was 6% and 3%, respectively. The popularization of solar technology discussed the importance of small solar home systems and solar lanterns in rural areas of the Global South and the impact on rural livelihoods and living standards [83]. The awareness and understanding of the common public about various renewable energy options needed improvement. The awareness and acceptance, particularly of people from rural areas, was not up to the desired level due to a lack of demonstration of the working of solar systems and knowledge needed to use solar energy products in daily life. The author stressed the importance of more research to bridge the gap between installation and implementation with a simple and clear demonstration of new technologies and imparting practical knowledge of proper maintenance of solar devices to the rural people to educate them about the value of solar energy. It can establish pathways for the economic and social progress of the rural population by providing a clean and efficient way to meet energy needs.

The utilization and constant up-gradation of solar energy-based artifacts was required to keep abreast of the latest trends and developments. Increasing awareness of renewable energy, promoting clean energy education, and building capacity to maximize solar utilization [3]. Proper solar energy education and skill development must be readily available, and solar training, teaching, and learning processes must be improved to promote renewable energy utilization. Education plays an essential role in the implementation of solar energy systems. It is equally as important to identify the people who are to receive and benefit from renewable energy education as it is to have a sound teaching methodology and training framework for capacity building. A discussion on a holistic method for assessing the success of renewable energy studies was made [84]. All stakeholders in the renewable energy study program share equal importance: students, technicians, lecturers, industries, researchers, mechanics, and entrepreneurs. Renewable energy education programs disseminate relevant knowledge and skills about the utilization of green energy for domestic and industrial applications. Hence, well-trained lecturers must handle it in student-friendly learning environments with the added input of expertise from professional experts to keep pace with current industry requirements.

A small prototype was designed and built solely to teach students about automatic solar tracking systems [85]. The prototype was built using open-source hardware and computer vision to test the control algorithms developed in Mathematica and Simulink. For effective learning, students need practical working knowledge. The simulations provided an excellent platform for students to study the theory and then explore the workings of the solar-tracking solar power system. The students learned much about increasing the efficiency and getting more energy from a solar panel and automatic tracking control and applications. The various factors that influenced the adoption of solar technologies in rural areas of Ethiopia for household energy needs were discussed by Guta [86]. The author found that modern energy technologies were practically non-existent in the Horn of Africa, necessitating the scaling up of realistic renewable energy programs that could meet the community's energy demand. The significant positive socioeconomic determinant factors were the size of the household, age, educational level of the people, occupational skills, household income, female-headed families, poverty reduction policies, and adult education.

The adsorption system was tested under different periods of mass recovery, heat recovery, and cogeneration to determine optimal operating conditions and technical viability [87]. The cogeneration performance of the selected system was studied at different heat transfer fluid (HTF) temperatures. The principles and practices of sustainable development must form an integral part of the higher education curriculum, particularly university studies, along with effective teaching and learning practices to establish a knowledge platform that will promote and popularize clean, affordable, and reliable renewable energy. The energy efficiency measures adopted by a Brazilian university worked towards achieving the targeted, SDGs were investigated [88]. The point of discussion was a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis for the setting of the SDG in the academic sector, particularly in HEI. The authors stressed the importance of educating and directing students who would be change-makers who work for a sustainable society. The focus was mainly on the transition to solar PV power generation. SWOT is a helpful tool to improve the adoption of renewable energy (RE) technologies.

HEIs play a crucial contributing role in the popularization of sustainable development by incorporating sustainability principles, values, and practices into the educational processes of teaching, learning, and research. The effects of the implementation of sustainable practices in the University of Minho were analyzed [89]. A mixed top-down and bottom-up approach was noted to be successful. The other measures were teaching and research, systematic collection, and data monitoring during the implementation of sustainability measures in HEI. Implementing sustainability policies within the institutional framework was used to formulate the guiding principles for executing strategies for a sustainable future. Abu-Rayash and Dincer [90] introduced a novel and comprehensive sustainability assessment model for energy systems. The model adopted an integrated approach that included many multidisciplinary aspects that affect an energy system, such as energy, exergy, economy, environment, society, technology education, and size of the RE systems. The model was applied to two case studies on solar PV and wind energy systems for 150 households in Ontario to meet their annual electricity, hot water, heating, and cooling needs.

An efficient bilayer wood solar steam generator and desalination system were simulated by Zhao et al. [91]. Almost all developing countries face the problem of increasing energy demand. Due to the pressing problem of climate change, attention must importantly be given to carbon dioxide mitigation and reduction of greenhouse gas emissions along with a capacity expansion of power production. The diffusion of RE in the electricity system for power generation was analyzed in Indonesia using a model used to determine the energy and carbon dioxide impacts of expanding a power system using a particular energy source [92]. It provided a clear picture of the optimal pathway of power system development. The total cost of electricity with the applied model was 4-10% lower than the electricity system without considering it. This target decreased CO_2 emissions by 25% compared to the reference scenario. This model estimated the capacity added, technology mix, cumulative electricity production and CO_2 emissions were reliable. Therefore, energy policies could focus on early deployment of renewable energy, upgrading of the variable RES grid capacity, and faster local learning to provide reliable and affordable electrical energy and ensure electricity access for the entire population of Indonesia.

The study showed no significant difference in students knowledge of RE based on gender, educational level of students, and parental education level [93]. Students pursuing vocational studies were more aware of RE than university students studying normal engineering subjects. Students believed Palestine has high wind and solar power potential of around 46% and 40%, respectively. Most of the students favored using solar energy for water heating purposes and felt that RE projects in Palestine could succeed. The authors recommended that RE concepts be incorporated into and form an integral part of the university and school curriculum to increase students' awareness and knowledge levels irrespective of their field of study or specialization. They felt that the education of young people was the key to popularizing the implementation of RE in an occupied country such as Palestine.

Many rural electrification schemes have been implemented in Indian villages at a low rate, under the ‘right to clean light for every child in rural India’. However, their impact and success/failure have not been examined. Sharma et al. [94] studied the learning outcomes, educational attainments, and the increase in study time of poor children with the replacement of kerosene lamps by solar lamps in rural households in four states of India using a purpose-based random sampling method. The total study time per day during dusk hours increased from 88 to 118 min as the off-grid solar lamps enabled the students to study for longer periods even in the absence of natural light. Daily study time was found enhanced by 32 min and 27 min for girls and boys, respectively. The influencing parameters of the total study time are several rooms in the house, the education level of parents, and the class in which the child was studying. The introduction of solar study lamps reduced the dependency on kerosene lamps. The students' study time and academic performance increased due to the use of solar lamps

in the households of economically weaker sections. The wide adoption of solar technology can transform the lives of poor and marginalized students by supporting their educational pursuits.
Passive solar heating in residential buildings has been investigated to alleviate energy poverty [95]. The clean technology of passive solar heating effectively reduced the waste of large amounts of conventional coal energy consumption and improved the indoor thermal environment in the renovated building. To meet the energy goals and alleviate energy poverty using passive solar measures, technical, economic, social, and policy issues must be given more attention. An assessment and quantification of the different environmental footprints (energy, carbon, and water) of a sustainable university campus, Keele University, United Kingdom, was carried out considering the university as a small community [96]. The campus has more than 250 buildings, 10,000 students and employs 3,000 staff, necessitating sustainable technologies, materials, systems, and approaches. The university implemented a combined environmental and energy policy to take concerted action within the sustainability framework. The findings serve as a reference for policy makers and practitioners making decisions based on studies on environmental sustainability in universities and other communities. There is a need for more favorable Governmental policies and more significant financial incentives. Such incentives are tax benefits and rebates to promote the extensive and rapid adoption of solar photovoltaic technologies and educational programs on the utilization of renewable energy to drive the nation toward sustainable energy [66]. Solar panels and wind turbines are energy technologies that are clean, renewable, and viable energy resource alternatives to the planet-warming effects of fossil fuels. Based on extensive interviews with women working in US and Canadian RE companies who are passionate about the environment, take proactive steps to stop its degradation, are committed to energy conservation measures and effectively address the developmental challenge of sustainability [97].
The efficiency of perovskite solar cells combining a thermally evaporated p-type perovskite layer was 21.38% [98]. It was due to the reduction in carrier recombination losses. Layered hybrid metal halide perovskites-ensembles of 2D perovskites domains were used to fabricate a low-loss LSC [99]. They achieved an optical quantum efficiency of 26%, a fourfold enhancement over the previously reported LSCs. High current density and output power (27 W) were achieved while maintaining high energy conversion due to a close electronic integration between the photo absorber and the electrocatalyst [100]. 2D-perovskite layer deposition using a slot-die process produced power conversion efficiencies (PCEs) of about 12.5% and 8.0%, respectively [101]. A new fluorine-substituted wide-bandgap small molecule non-fullerene acceptor used in tandem with solar cells produced a PCE of 15%, the energy loss was 0.63 eV [102]. The review on organic-inorganic halide perovskite solar cells with PCE rose from 3.8% to over 23.3% [103].
Recently, the broad solar absorption and high conversion efficiency of photothermal materials were reviewed by Gao et al. [104]. The utilization of sunlight as a RE source for clean water production is a fast-growing research area. It is a promising approach to provide solutions for clean water scarcity with minimum environmental impact. Green solar-driven water vaporization technology has regained the attention of researchers as an efficient and sustainable solution to water scarcity. Approximately 1-20% of the energy has been generated from RES to engage buildings, machinery, and equipment [105]. Solar PV was the major share towards sustainable energy. Energy analysis was carried out on sustainability and energy use at Texas State University [106]. They conducted financial analysis of selected sustainable energy projects. The results are reduced energy use and commitments towards sustainability at the smaller institution level and a more extensive level among all the sustainable energy stakeholders. The teachers' adoption of solar PV systems to promote a sustainable culture was investigated [107]. The knowledge and attitudes of the teachers were improved towards sustainable ways in daily life.

- Solar Thermal Energy Technologies

Nonconcentrated solar thermal technologies are beneficial for water heating and air heating applications. Solar concentrated collectors can produce a high temperature on the point focus solar receivers. The energy storage density of the concentrated solar receiver with a parabolic dish collector was investigated [108–110]. The concentrated heat flux was absorbed and stored at the solar receiver using phase change materials. Hence, such solar receivers can provide the thermal buffering effect to compensate for the short time unavailability of solar rays due to passing clouds and act as a mobile heat battery for later uses. This work is helpful to the students to understand integration issues of the solar collector and thermal energy storage in outdoor experiments.

- Implementation of solar energy

The deployment policies of different early-stage energy technologies must be framed based on specific applications rather than generic deployment policies [111]. The authors observed two Germany's solar

photovoltaic feed-in tariff policies, namely technology-specific and application-specific policies, to accelerate photovoltaic growth. The implications of implementing solar projects in Africa were assessed towards implementing the 2030 plan [112]. The lack of performance assessment methods of the solar power project is one of the major concerns in implementing RE projects in Africa based on case studies on Ghana, Kenya and South Africa. China's solar photovoltaic power was studied using a model to explore its development during 2018-2050 [113]. Learning and technological progress are the main factors in reducing the cost of solar PV power. The use of a solar home system as a source of electricity in remote areas in Côte d'Ivoire was analyzed by Diallo and Moussa [114].

The solar home system practice improved the per capita energy consumption, increased schooling, and reduced illness. The influencing factors for rooftop solar panel installation were income, education, knowledge about Australia's RE policies, and conviction about the environmental benefits of solar energy [115]. Australia enjoys the distinction of having one of the highest rates of installed residential rooftop solar systems globally, with over 20% of households favoring the same. The use of solar energy by deploying solar PV in rural households in India was analyzed by Yadav et al. [116]. The high satisfaction observed for distributed solar PV among the households who were received subsidized PV connections paid connections from solar microgrids and purchased solar energy systems for power reliability. Table 2 shows selective applications of innovative research and developments in various fields.

Table 2. Recent innovative applications through solar energy research and development.

Solar energy system	**Innovative applications**
Solar thermal	Fluidized bed and bioreactors [117,118], absorption chillers [119], Hydrogen fuel and ammonia production [86,120,121], energy efficient buildings [20,122], Fuel cells [123], iron ore agglomeration [124], wastewater treatment [125], medical sterilization [126,127], cooling of building by triple vacuum-glazed windows [128]
Solar PV	Smart textiles [129], agrivoltaic system [130,131], electric vehicles [132], flexible solar cells [133], road structures and marine applications [134,135], hybridization with biogas system [136], solar home systems [137].

Results and discussion

RES has the potential to offer solutions to long-standing energy problems and environmental concerns. Many countries such as Germany, Sweden, and China have actively focused on solar energy education and training to understand the possibilities of renewable energy and move to green technology for energy security. Besides encouraging research on energy efficiency technologies and best energy practices to help respond to the challenges of mitigating global climate change. Solar energy education and training can be successfully implemented only when other equally essential skills like verbal and written communication, teamwork, business, and project management are also imparted. The requisite technical skills for young engineers are the primary factors to become successful solar energy professionals.

Only a few countries are actively promoting solar energy education to scale up solar energy generation, advance solar photovoltaic technologies, and increase economic PV deployment on a large scale to achieve greater sustainability. Strategies must be adopted to reach out the benefits of solar power energy and promote the utilization of solar power systems for meeting almost all thermal or electrical energy requirements. Exploring new and more effective applications of solar energy systems and grid technologies that are both technically viable and financially sustainable will ensure continuous improvements in providing efficient and affordable alternative energy for homes and commercial buildings, paving the way towards sustainable cities and countries.

The drivers, barriers and enablers of end-of-life solar PV panels and battery energy storage systems [138]. Economic drivers are dependent on the research and development of educational institutions and industries. The barriers are related to the lack of profits/collecting network, and no regulations/ incentives. The high school students were motivated to learn new concepts by fabricating a handmade solar cell [139]. Such solar cells consist of chlorophyll extract from the leaves of Diacol Capiro potatoes and nickel-silver electrodes. The students learned the making of low-cost natural dye to make a solar cell. An individual chlorophyll cell produced a maximum voltage of 1 V. Thus, around 90% of the students learned to use visible light to produce electricity.

The willingness to pay towards renewable electricity in rural households in Ethiopia was analyzed because 55% of the people were with lack electricity [140]. Compared to hydroelectric dams, solar photovoltaic energy is preferable to rural electricity in Ethiopia. The benefits of solar photovoltaic systems for low-income families in Korea were discussed by Lee et al. [141]. The people were satisfied with the utilization of solar energy. However, the mismatch between the PV capacity and the electricity bill reduction should be considered in the long-term analysis with a balance of systems. Estimated gross career opportunities for solar PV, wind onshore and offshore deployment were up to 2050 for the European Union [6]. For the analyzed period (2014-2050), the photovoltaic sector possibly provides more careers in operation and maintenance. Table 3 shows the various activities required to reach sustainability through solar energy education, serving as clean energy for all.

A model was designed to demonstrate high-efficiency maximum power point tracking (MPPT) with intelligent controllers [142]. MPPT helps achieve maximum output from a PV panel, ensures that the solar PV system is used effectively, and improves the solar conversion efficiency; the demonstration was aimed at PV engineers and researchers. The focus of the training program was to give fresh engineers access to better employment opportunities and equip them with the necessary know-how to be eligible to work on start-up projects on power point tracking. Quantum dot solar cells are promising organic methods of solar energy conversion [143].

Students must gather knowledge of RE systems in any country with solar energy potential considering three significant aspects: energy source, environment, and economic aspects. The solar energy industry needs enterprising students who possess multidisciplinary skills to be involved in research activities to explore new generic or specialized solar system designs that are cost-effective for commercialization to meet societal needs and for the continued growth of this field. The power of the current generation to bring about a solar revolution to meet future energy needs lies in the hands of the current generation.

Table 3. Activities for promoting solar energy utilization.

Items	**Description**
Government policies	The Central and State governments must adopt a broad policy framework and its programmes, incentives, fund subsidies, and promotional activities to favor capacity addition and people to adopt solar energy-based utilities.
Mandatory courses at undergraduate levels for science programs	Greater awareness of the urgent need for sustainability, increasing knowledge of solar energy systems and skill development in the student community.
Activity-based curricula and multidisciplinary skills	All educational modules are embedded with project-based practical activities such as power kits and solar products to inculcate multidisciplinary skills [81].
Industry-Institution Collaboration	Industries and institutions should work closely with research centers and academia for mutual interaction to address sustainability issues and strive towards eco-friendly energy generation and use [36].
Outside classroom activities	Providing more hands-on activities and experiments outside the classroom leads to a better conceptual understanding of solar energy principles. It also facilitates involvement in renewable energy-related projects.
Research and development of new technologies	Pioneering research activities and development efforts are underway to make the best possible use of RE, materials, design of energy-efficient systems, improving products and manufacturing processes, and competitive costs.

It is essential that solar energy professionals could possess multidisciplinary knowledge for more significant solar deployment, increasing solar adoption, and improving solar installations. Novel solar energy materials and efficient energy storage conversion technologies can lead to sustainability [144–147]. Access to clean, affordable, and reliable energy as thermo-electric needs constitute a significant portion of the energy requirements. The SDGs were outlined in the 2030 Agenda for Sustainable Development of the United Nations

to guide a sustainable future. Sustainable and affordable energy is one of the 17 goals to ensure access to reliable energy [148]. New energy storage materials and system designs are evolving to store solar energy effectively in electrical and thermal energy storage to meet the energy needs of society [149–154]. The record performance of different solar cell technologies is shown in Figure 7. Solar energy technologies can provide input to several indicators of other SDGs, such as water, a decent work environment, and others.

Solar energy is an ideal sustainability model as it can help reap the benefits of a green economy by providing clean energy. Solar energy education should systematically provide fundamental knowledge of solar technology and photovoltaic applications, a good understanding of concepts and principles, skill development, and vocational training programs to undergraduate students to empower them to face various challenges and opportunities in solar energy. Undoubtedly, solar power generation is one of the fields that provide more job creations in installing and maintaining solar PV plants and the research careers in solar energy materials development.

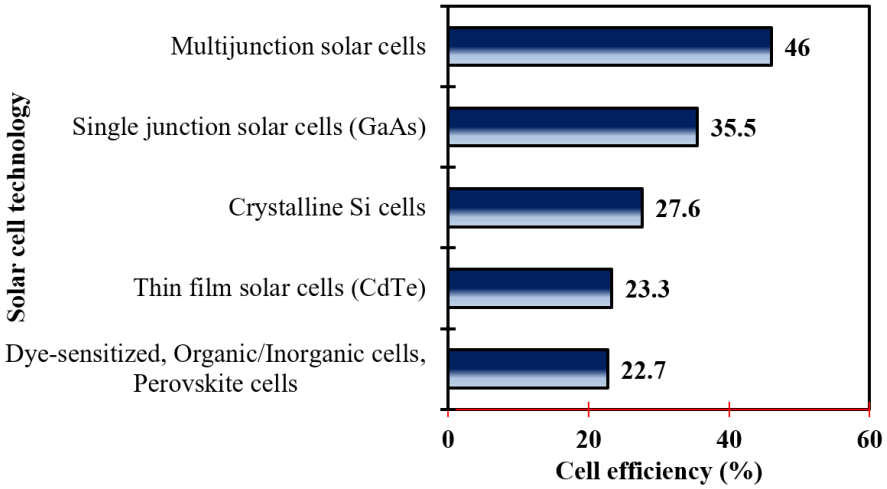

Figure 7. Solar cell technologies and their respective recorded efficiencies.

The notable barriers are lack of awareness, financial policies, reliability, and end-of-life management practices towards a circular economy. The drivers are governmental policies, financial assistance, incentives, reliability and maintenance measures, energy consciousness, climate change mitigation, and environmental benefits. Further developments in solar energy require developing more reliable and sustainable energy materials for energy conversion and storage. Solar energy technologies must be strengthened to provide clean water through effective desalination, clean air through solar-powered carbon capture methods, thermal management of buildings, and wastewater treatment technologies [155–158]. Implementation of such green technologies can create more jobs and sustainable energy infrastructure [159]. The interlinking of other SDGs with SDG 7 has already gained momentum, and it is essential to increase the implementation rate to meet the climate change goals of 2030. The Effective solar thermal conversion technologies are to be strengthened for the thermal energy requirements to provide uninterrupted energy needs from the domestic to the community level and power generation.

Impact

The impact of the present short review article comprehensively discusses the recent trends in solar energy-based education and research as per the recently published documents. Several measures and institutional initiatives were undertaken in solar energy education to provide awareness and hands-on solar energy technologies. The topic-wise published documents are shown to understand the recent solar energy-relevant work carried out by several researchers to motivate the solar community to bring out more such solar energy innovations in education and product innovations. To improve the use of solar energy to the maximum possible extent, imparting proper knowledge promptly at the institution level is essential with solid motivation towards sustainability.

Solar cells are primarily investigated area in solar energy research. Various solar photovoltaic and cell technologies are continuously studied globally to improve cell conversion efficiencies and reliability. Research on novel materials should focus on the reliability and sustainability of large-scale deployments. Furthermore, solar cell research activities should combine with advanced developments in sustainable energy materials

to witness sustainable development. The need-based poly-generation systems using solar energy are vital to simultaneously minimize environmental degradation by satisfying thermal and electrical needs.
The present review sheds light on the recent innovations in solar energy from a country's perspectives on the learning environment and product development. The discussion and future directions are incredibly beneficial to all the stakeholders of the solar community. The immediate impacts of effective solar energy utilization are social interconnections, economic opportunities, environmental security, and financial benefits. In addition, solar energy utilization satisfies one of the 17 sustainable development goals, 13-climate action, by minimizing fossil fuel usage. The discussion of the present review could help the sustainable energy community to explore more reliable products for society with minimal carbon footprints in the long term.

Conclusions

Solar energy is evidently a key to a sustainable future. It can effectively meet a significant part of the energy demand without the undesirable repercussions of environmental degradation, carbon emissions, and global warming and meet SDG 7 and 13. The major conclusions are given below.

- Proper solar energy education and research strategies can spearhead a country's efforts to achieve its sustainability goals and ensure sustainable living for its citizens and the earth.
- The strengthening of green campus initiatives in each institution plays a pivotal role in RE explorations.
- Courses related to RE must focus on various topics and issues related to solar energy, which should be a core course in science and engineering curricula to utilize solar energy for daily energy needs.
- Learning by doing like activity-based learning is effective to learning solar technologies.
- Research work is continually needed in the solar photovoltaic field to promising alternative energy. The flexible and organic solar cells require more research to produce stable solar cells with higher efficiencies.
- Several potential applications of solar energy are to be explored with reliable energy storage technologies.
- Emerging solar cell technologies are demanding research on developing low-cost and sustainable energy materials.
- Thermal management of concentrated solar PV and subsequent poly-generation needs improvement.
- Hybridization of other energy technologies with solar energy systems is helpful to alleviate variable and intermittent solar radiation.
- Integration of computing smart technologies into solar energy systems can reach and benefit society.
- Promoting SDG 7 with other closely associated SDGs can lead to materializing the carbon-free environment.

Solar energy can help meet the energy needs of the future and resolve the energy crisis with its high energy saving potential and minimize adverse impacts on the environment. There must be greater dissemination and awareness of the many advantages of using solar energy, such as improved environmental quality, increased energy stability and security, and local economic development benefits to accelerate the shift to clean energy. Cost-effective solar energy technologies with energy storage systems and products can underpin progress in all areas of development and go a long way in powering a future with easy access to reliable, affordable, completely sustainable clean and green energy for all.

Abbreviations

AEE	Alternative energy engineering
DSSC	Dye-sensitized solar cells
HEI	Higher education institutions
HTF	Heat transfer fluid
LSC	Luminescent solar concentrator
MPPT	Maximum Power Point Tracking
PCE	Power conversion efficiencies
PV	Photovoltaic
RE	Renewable energy
RES	Renewable energy sources
SDG	Sustainable development goals
STEM	Science, technology, engineering, and mathematics
SWOT	Strengths, Weaknesses, Opportunities, and Threats

Conflict of interest
The author declares that there is no conflict of interest.

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GOVERNMENT EARLY POLICY RESPONSES ON COVID-19 CHALLENGES IN CENTRAL AND EASTERN EUROPE: SME SUPPORT

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Highlight
The study evaluates policy response mechanisms in terms of measures regarding enterprise size.

Abstract
The main aim of the given research is to analyse Government policy early response due to the Covid-19 crisis in Central and Eastern Europe regarding SME support. The research methodology is based on an analysis of the pandemic impact on key indicators of countries development as well as an analysis of SME support policies responses by selected countries (Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovenia and Ukraine). The dynamic trends of Covid-19 spread and its impact on macroeconomic indicators were analysed. The negative growth of GDP, as well as current account balance and increasing gross debt burden, were explored in all analysed countries and the policy responses were the required measures to avoid possible economic collapse. Implemented measures were mainly directed to achieve economic recovery and capturing stability, but the main focus of the research is to analyse the support policies according to the criterion of enterprise size, SME in particular. The study is based on country-level data as well as on individual State Aid cases of each analysed CEE country. It allowed to evaluate policy response mechanisms in terms of measures regarding enterprise size. Although SMEs suffered the most during the crisis, CEE countries spent most of their resources on supporting companies, regardless of their size.

Keywords
SME; COVID-19; government support; public finance.

Introduction

The greatest challenges for the global community have been revealed in the year 2020. The spread of the detected unknown coronavirus has led to an incredible health crisis all over the world, that has had unparalleled and significant impacts on all aspects of daily lives covered by such spheres as communication, work, production, trade, consumption and general life habits.

On the 11th of March 2020, the World Health Organization (here and after WHO) proclaimed a pandemic caused by an extremely infectious and transmissible coronavirus disease called "Covid-19" [1], signalling its global spread. The mentioned pandemic has resulted in not only a crisis in the social and welfare system but also disruption of the macroeconomic stability all over the world as well as the financial sector and business. Such impact of Covid-19 on the economic situation has required governmental immediate measures as a newly established policy response to support not only the health system but financial and economic stability as well.

The given research is mainly focused on the analysis of policy response regarding business support in Central and Eastern Europe (here and after CEE), in particular in Bulgaria, Hungary, Czechia, Poland, Romania, Slovenia and Ukraine to reveal the existence of some dependence between the development level of countries and the budgets of support measures. More recent attention has focused on the issues of the COVID19 influence on different spheres of life. The academic literature on COVID 19 has touched on the emergence of several themes: business, social contacting, education, medicine, public government. Some general papers describe the impact of COVID 19 on the business, economy, people etc. [2]. As an overview of the SMEs' problems, the article gives information about issues in general.

In most literature country and regional specifics of getting over the crisis are linked to COVID-19. For instance, Cohen's test results which are applied to public companies' performance at capital market assess that public policy performance in the COVID-19 period is successful in boosting the market of Indonesia [3]. Some research papers are devoted to the issues of human rights abuse in the context of COVID-19 and describe the impact of anti-crisis policies in the EU correlated to this problem [4]. Partly this point of view can be noticed in research [5] that in general, some government restrictions on local levels in EU countries had positive effects, however in global meaning, such measures had not a significant impact. The consequences of early response in Southern American countries are studied by [6]. He relates economic resilience and the number of deaths. Moreover, the author admits that Uruguay and Paraguay have managed to contain the coronavirus crisis, while Brazil and Peru appear to be overwhelmed in mid-May. The early projections and a novel burden index are used for the assessment of the pressure on the health systems.

Norrlöf tries to answer the question of whether the COVID 19 is a liberal and democratic curse [7]. She argues about the level of mortality in the countries with liberal democratic regimes in comparison with other countries. She claims that in liberal democratic countries the infection spreading of coronavirus is higher, however, the level of mortality is lower. Here she confirms the fragility and relativeness of economic openness as well.

Some scholars emphasize that intergovernmental responses to pandemics are even more effective than general government responses and show the example of anti-COVID 19 policies [8]. For better risk-management related to pandemic or other force major situations response, it is offered to use the reverse system: from local levels to regional ones and from regional levels to national during the development of public policy in the healthcare system [9]. Indian scientists argue that strong measures of overcoming COVID 19 and suggest that step by step ones are more effective [10]. This study shows the importance of government measures for small and medium enterprises, performed by stage by stage.

Another direction of the studies is focused on the state support instruments for the business (including SMEs). For example, there are papers related to debates about what areas should be supported by the government and which ones do not need them [11–14].

Some papers emphasize the importance of the volunteer performance of the business. The role efforts of medical personnel, SMEs representatives and ordinary people alongside strong measures of public authorities is emphasized in fighting with COVID-19 and its consequences [15]. Other studies prove that in overcoming COVID 19 the cooperation between policymakers, businesses, medical representatives, the population will be an effective tool [16].

Burdick, W., Dhillon, I. [17] claim that the coronavirus situation is said to have led to a revision of approaches to the accreditation of medical education and the emergence of new medical specialities needed to combat the pandemic. In this sense, educational institutions have become more sensitive to such changes [18].

At the same time, the not only government should care about it, but another study also shows [19–21] that SMEs mitigated the risks related to COVID 19 using digital instruments. The digitalization of SMEs could make a strong response to the COVID crises.

The importance of true information about policy response COVID 19 which is translated from different sources of media is emphasized in the study of Hurtley and Vu, [22]. It is proved that news has an impact on the economic

behaviour of consumers. This makes SMEs revenues extremely sensitive. Some scholars claim that COVID -19 will affect the trade of high-tech production and it will make a certain impact on the execution of the Association with the EU [23–25]. Therefore, the policy response is extremely important to be discussed on a high level. Therefore, the asymmetry of information should be also reduced.
There are studies with a futuristic view about post-pandemic life and some suggestions of new forms of business, governance and relationship [26].
The main aim of the research is to conduct an analysis of the Government policy early responses due to the Covid-19 crisis in CEE regarding SME support.

Methods

The study of policy responses on the Covid-19 crisis regarding SME support is conducted in two stages. Firstly, an analysis of the pandemic impact on key indicators of countries development was made. As an indicator of the country's pandemic exposure the dynamics of new Covid-19 cases from April to September was. Also, historical indicators and forecast values of key macroeconomic indicators are analysed: Real GDP growth rate, Inflation rate change, %, Current account balance, % of GDP, General government gross debt, % of GDP. It allowed assessing the macroeconomic situation of CEE countries before the crisis, as well as prospects for development in the next three years.
In the second stage, an analysis of SME support policies responses by country was performed. For this purpose, the individual State Aid of CEE countries were studied. The total sample was 93 cases from April 3 to October 15, 2020.
A detailed study in terms of the following specific mechanisms was conducted. Additionally, a comparative analysis of support methods in terms of company size was performed. For this purpose, the mechanisms were classified as follows:

- those that apply to all companies regardless of their size;
- those that apply only to large companies;
- those used for large and medium-sized companies;
- those used for micro and small companies;
- other methods - for example, ad hoc cases.

Data used for research were both quantitative (historical and forecasted data of macro indicators; statistics new Covid-19 cases, the amount of the government support) and qualitative (individual cases of state aid).

Results and discussion

As well known, the Covid-19 crisis has redefined economic and social policies in every country almost all over the world. Policy responses due to the Covid-19 crisis have had numerical implications as in social and welfare spheres as well as fiscal, monetary and financial sectors. Policymaking was faced with ongoing Covid-19 pandemic spread on a global scale which leads to such policy initiatives as full lockdown of business activities in trade, entertainment, tourism sectors, services etc., but even in stock and financial markets. The negative circumstances of such measures in an unemployment rate, GDP decrease, consumer prices index and budget deficit growth have been detected.
The general trends of Covid-19 growth in dynamics for selected countries are shown in Figure 1. For getting comparable data, total cases were estimated per 100 K of the total population in a particular country.

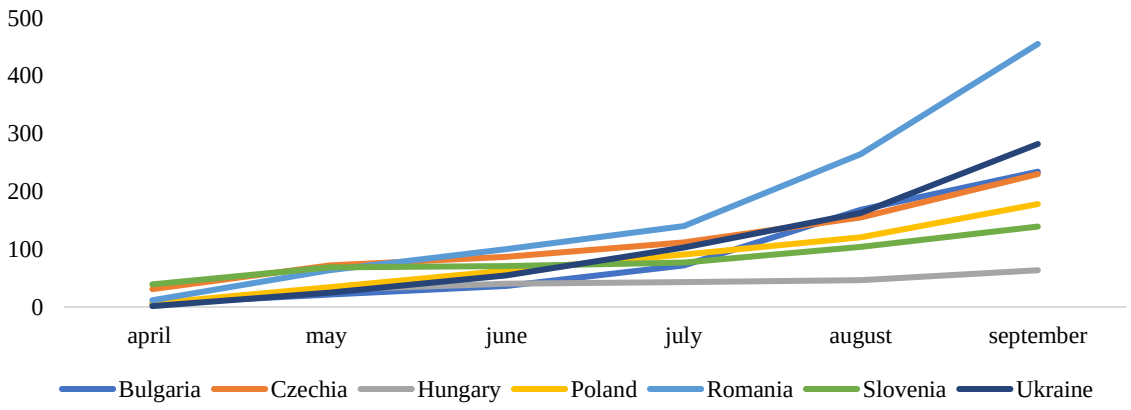

Figure 1. Total Covid-19 cases per 100 K of population on the 1st of every month. *Source: [1,27]*

Though, at the beginning of the pandemic spread in Central and Eastern European countries the majority of Covid-19 cases were detected in Slovenia, Czechia and Romania during April till June of 2020, at the same time the great share of deaths was fixed in Hungary (app. about 10 %, which twice exceed the average Covid-19 death rate in the other analysed countries). During the period July-September 2020 the most numerical cases of Covid-19 per 100 K of the population were registered in Bulgaria, Ukraine and Romania.
The dynamics of new cases appearing show, that cases Czechia was the leader according to the criterion of new cases per 100 K of citizens on the 1st of April at the beginning of the pandemic, but on the 1st of October the situation has been changed and Ukraine and Romania have the most numerical new cases among analysed countries, more detailed on Figures 2-3.

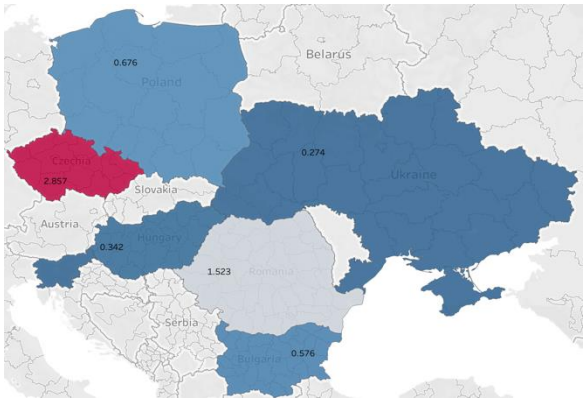

Figure 2. New cases per 100 K of population on the 1.04.2020
Source: [1,27]

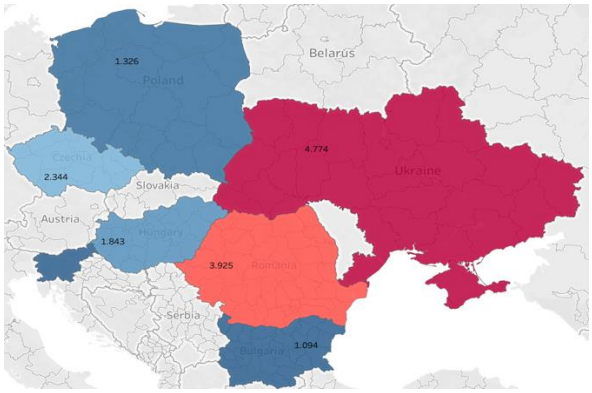

Figure 3. New cases per 100 K of population on the1.09.2020
Source: [1,27]

Along with general Covid-19 trends, the great importance has macroeconomic indicators and possible Covid-19 impact on it to reveal if the more developed countries considering its macroeconomic stability establish more effective measures as policy responses to support SMEs and their further development.
One of the main indicators which define the level of country economic potential is Real GDP growth and inflation rate, the annual per cent change of these parameters are shown in Table 1 and Table 2.

Table 1. Real GDP growth, %. *Source: formed by authors on the basis [28]*

Country	**2017**	**2018**	**2019**	**2020 (1st half)**	**Forecast**		
					2021	**2022**	**2023**
Czechia	5.2	3.2	2.3	- 6.5	5.1	4.3	4
Bulgaria	3.5	3.1	3.4	- 4	4.1	3.7	3.2
Hungary	4.3	5.1	4.9	- 6.1	3.9	4	3.8
Poland	4.9	5.3	4.1	- 3.6	4.6	4.5	3.7
Romania	7.1	4.4	4.1	- 4.8	4.6	3.9	3.8
Slovenia	4.8	4.1	2.4	- 6.7	5.2	3.4	2.8
Ukraine	2.5	3.4	3.2	- 7.2	3	3.2	3.4

Table 1 shows that 1st half of 2020 is characterized by the negative flow of GDP growth, which confirms the fact that the Covid-19 pandemic has a great impact on the economic development of every country. Ukraine, Slovenia and Czechia have the most GDP reduction in 2020 and the lowest level of GDP reduction is revealed in Poland. Considering the data of IMF forecast, the highest growth rates of GDP are predicted for Czechia and Poland, at the same time the lowest ones – for Ukraine and Bulgaria.
Analysing the data of Table 2, the highest inflation rates are typical for Ukraine for a period of 2017-1st half of 2020, the most stable situation with inflation rates is typical for Slovenia and the forecast data demonstrate a trend of gradual decrease of inflation growth in 2021-2023 for all analysed countries.

Table 2. Inflation rate change, %. *Source: formed by authors on the basis [28]*

Country	2017	2018	2019	2020 (1st half)	Forecast		
					2021	2022	2023
Czechia	2.5	2.2	2.9	3.3	2.4	2.2	2
Bulgaria	1.2	2.6	2.5	1.2	1.7	2.1	2
Hungary	2.4	2.8	3.4	3.6	3.4	3	3
Poland	2	1.6	2.3	3.3	2.3	1.9	2
Romania	1.3	4.6	3.8	2.9	2.5	2.7	2.7
Slovenia	1.4	1.7	1.6	0.5	1.8	1.7	1.8
Ukraine	14.4	10.9	7.9	3.2	6	5.7	5.2

And the next indicators, which are relevant to analyse in the context of Covid-19 impact on the macro level, are current account balance and gross debt, which dynamics is shown in Table 3 and Table 4.

Table 3. Current account balance, % of GDP. *Source: formed by authors on the basis [28].*

Country	2017	2018	2019	2020 (1st half)	Forecast		
					2021	2022	2023
Czechia	1.6	0.4	-0.4	-0.7	-0.5	-0.4	0
Bulgaria	3.5	1.4	4	1.9	2.3	2.2	0.6
Hungary	2.3	0	-0.8	-1.6	-0.9	-0.6	-0.5
Poland	0	-1	0.4	3	1.8	0.6	0.2
Romania	-2.8	-4.4	-4.6	-5.3	-4.5	-4.2	-4
Slovenia	6.2	5.9	5.7	4.5	3.9	3.2	2.1
Ukraine	-2.2	-3.3	-2.7	4.3	-3	-3.9	-3.7

Table 4. General government gross debt, % of GDP. *Source: formed by authors on the basis [28].*

Country	2017	2018	2019	2020 (1st half)	Forecast		
					2021	2022	2023
Czechia	34.2	32.1	30.2	39.1	41.4	42.5	42.8
Bulgaria	23	20.1	18.6	24.1	23.7	22.2	21
Hungary	72.9	70.2	66.3	77.4	75.9	73.2	69.8
Poland	50.6	48.8	46	60	60.2	59.2	59.3
Romania	36.8	36.4	36.8	44.8	49.6	54.4	58.5
Slovenia	74.1	70.4	66.1	81	78	77.3	75.5
Ukraine	71.6	60.6	50.1	65.7	64.3	61.8	58.2

Table 3 demonstrates the trend that such countries as Romania and Ukraine have negative current account balance during almost all analysed periods and data of forecast for these countries are not an exception. The most stable indicators of current account balance were in Bulgaria and Slovenia, as well as forecast tendency. As for the tendency of government debt as a percentage of GDP, the main debt burden was fixed in Slovenia, Hungary and Ukraine and a negative tendency is captured through the forecast period of 2021-2023 for the mentioned countries. The lowest level of gross debt is typical for Bulgaria and Czechia. So, after analysing the main trends of the macroeconomic situation, as well as Covid-19 dynamics in Central and Eastern Europe, it is relevant to explore the governmental measures for economic recovery and capturing stability to reveal the possible dependence between economic conditions, Covid-19 spread and effectiveness of policy responses.

Policy response on COVID crisis in CEE.

The crisis has caused an intensification of policy responses across the EU. According to our analysis of selected European countries, the highest level of support ranges from 21% in France to 39% of GDP in Germany. Instead, in CEE countries, the level of support was much smaller due to limited budgetary capacity (Figure 4).

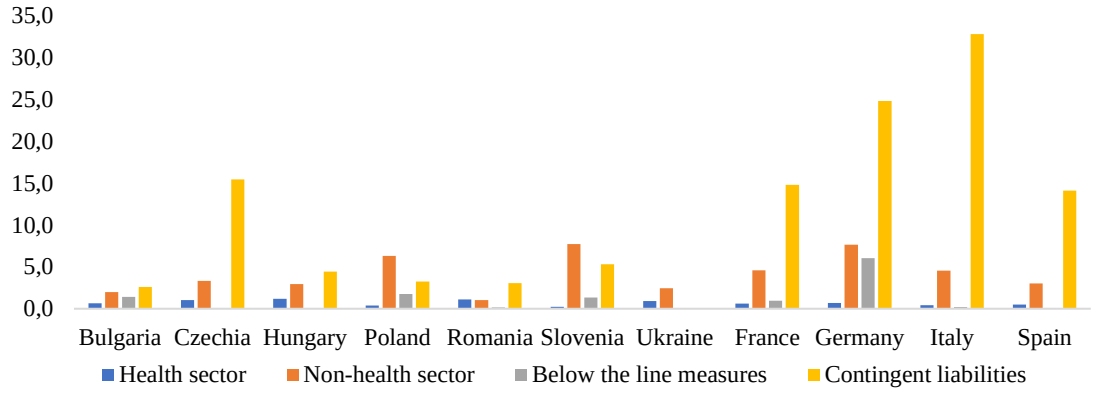

Figure 4. Fiscal responses of selected European countries (as % of GDP). *Source: [28].*

The Czechia and Slovenia provided the highest levels of support – 20% and 14% respectively, while Romania and Ukraine provided the lowest levels of support.

The largest amounts of support are provided through the contingent liabilities channel, in form of credit guarantees. This type of support does not require direct costs from the budget, but instead plays the role of a safety net for the economy and ensure the necessary level of business viability.

The next stage of the study was the analysis of individual cases of state support of the analysed countries.

According to our analysis, CEE countries have chosen different strategies of economic support. For example, Bulgaria has focused mainly on direct financing of companies, regardless of their size, operating in the service sector (hotels, preschools, transportation, etc.). Direct grants under this program account for more than 70% of all funds allocated to support the economy (Figure 5).

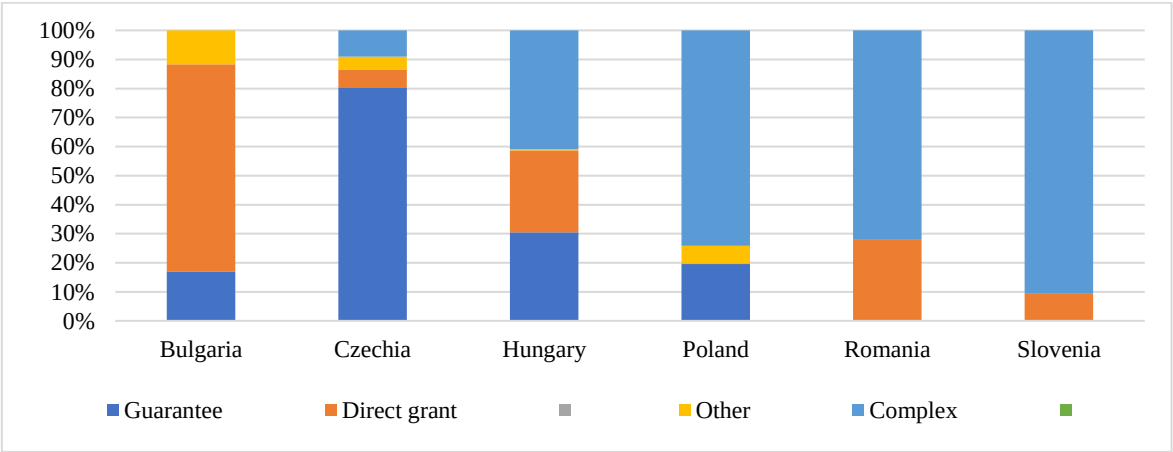

Figure 5. Distribution of response policies by CCE countries, %. *Source: [29].*

About a third of the total support package is made up of grants in Hungary and Romania. Such grants in both countries are aimed primarily at maintaining the liquidity of companies, regardless of their size and type of activity.

Data shows, that Poland, Romania and Slovenia widely applied comprehensive economic support measures: such programs include several support mechanisms to the companies that meet certain criteria. Such measures are usually aimed at improving access to credit and include guarantees, soft loans, interest subsidies, and in some cases direct grants. The use of such comprehensive mechanisms reduces the time spent on policy coordination with the European Commission and responds more quickly to the challenges of the crisis.

Although most countries have focused on measures targeting all companies, regardless of size, governments have also implemented special measures for individual companies (Figure 6).

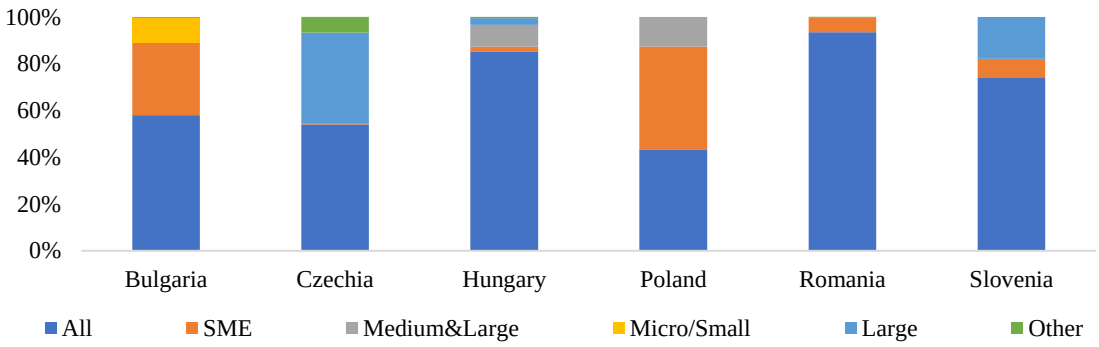

Figure 6. Policy response of CEE countries in terms of companies' size, %. *Source: [29].*

Evidence suggests that countries have often used comprehensive mechanisms to support SMEs. A detailed analysis shows that mainly they include mechanisms of direct support in the form of grants and credit financing. In particular, Poland has launched a program to support SMEs in the amount of 16.6 billion euros in loans and repayable advances.

In addition, as noted above, Bulgaria launched a direct grant program for micro and small companies in October. It is noteworthy that grants can be provided to companies that were in danger of bankruptcy at the end of 2019.

Table 5. Policy response of CEE countries in terms of companies' size and mechanisms. *Source: [29].*

Mechanism	**Company size**					
	All	**SME**	**Medium & Large**	**Micro&Small**	**Large**	**Other**
Guarantee	29.3%	1.3%	91.0%	0.0%	93.8%	0.0%
Direct grant	9.9%	1.4%	9.0%	100.0%	4.4%	4.3%
Other	7.2%	0.9%	0.0%	0.0%	1.8%	62.7%
Comprehensive	53.5%	96.4%	0.0%	0.0%	0.0%	33.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

The analysis showed the existence of distribution between support mechanisms depending on the size of the company. Thus. purely SMEs are supported by governments through direct financing mechanisms. While for large companies, governments are more inclined to apply the Contingent liabilities mechanism (in particular. through the provision of guarantees to financial institutions).

Case of Ukraine.

Compared to CEE countries, the list of measures for companies supports in Ukraine is much narrower and focuses mainly on the provision of state guarantees. First, the Government has modified the existing program to support small and medium-sized businesses in the form of reduced lending rates and the provision of guarantees. As of October 2020, according to the Ukrainian Ministry of Finance, the total amount of guarantees provided was approximately EUR 300 million.

Also, to support business in the context of the pandemic Covid-19 in April. amendments to the Law on the State Budget for 2020 lifted restrictions on providing guarantees to public and private companies for investment and infrastructure projects aimed primarily at road construction (mainly it affects large companies).

The key difference between the use of this tool in Ukraine and the EU is safeguarded. EU countries support mainly those companies that were stable and carried out effective economic activities before the crisis. In Ukraine, on the other hand, the requirements for assessing the financial condition of borrowers are much lower, and sometimes even non-existent. This situation can eventually lead to an increase in NPLs and an additional burden on the budget.

According to analysed policy responses, applied in CEE countries, the most relevant of them, considering modern conditions of the Ukrainian economy, should be as follows: direct and indirect financing in the form of guarantees as well as comprehensive measures including business lending.

Impact

The issues raised in the research are mainly focused on social and economic impact of Covid-19 in some countries of Central and Eastern Europe, exemplified as challenges in such spheres as health, society sustainability. as well as macroeconomic stability and the level of economic development on national level due to pandemic. The policy impact regarding SME support is the measured in the research by analysis of policy responses on Covid-19 challenges since SMEs are the main drivers of economic development on national. regional and local level.

Conclusions

CEE countries have allocated less funding to support the economy compared to developed EU countries. This is partly due to lower numbers of Covid-19 cases in spring (compared to Italy and Spain), partly due to limited budget resources (compared to Germany). In the second phase of the crisis, these countries are in a relatively better position: the projected GDP growth rate is higher than the European level, and the share of public debt is lower. This situation provides a certain margin of safety and additional resources for further business support. An analysis of existing support mechanisms has shown the heterogeneity of business support policies within CEE. Thus. Bulgaria mainly uses direct financing, the Czech Republic - indirect financing in the form of guarantees, while the rest of the countries have introduced comprehensive measures that combine several mechanisms aimed primarily at boosting business lending. The policy response of the Ukrainian government was mainly focused on providing state guarantees and reduced lending rates.

Besides, the only country that has introduced substantial support programs for SMEs in Poland, the rest of the countries have focused on supporting all companies, regardless of size. Under such conditions, it is critical to continue to effectively support business, including SMEs. Large companies are important for the state budget in terms of tax payments and export earnings. However. SMEs play a major social role alongside a purely economic one.

Conflict of interest

There are no conflicts to declare.

Acknowledgments

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MECHANICAL PROPERTIES EVALUATION OF BANANA FIBRE REINFORCED POLYMER COMPOSITES: A REVIEW

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Abstract
In today's fast-developing world, the use of composite materials is closely related to environmental pollution, renewable and biodegradable resources. A researcher is looking for environmentally friendly materials. Natural and synthetic fibres come in a wide range of shapes and sizes. Natural fibres include jute, straw wheat, rice husk banana fibre, pineapple leaf fibre, cotton, Sisal, Coir, Oats, and Bagasse. Every year, 13.5 tonnes of banana fibre are produced in India. Teabags, paper, and polymer composite reinforcement are just a few of the applications for banana fibre. This article focuses on the manufacture of banana fibre with epoxy and a variety of other natural fibres. By combining banana fibre with some current technology, waste will be reduced, and energy efficiency will be increased, all while supporting sustainability. Banana fibres are covered in this work, along with their uses, applications, and mechanical qualities, as well as how banana fibre might improve mechanical properties.

Keywords
banana fiber; epoxy; mechanical testing; composite material; natural fiber.

Introduction

When compared to other fibres, banana fibre offers superior mechanical qualities. Banana fibre has a higher specific strength than glass fibre. Until today, we couldn't completely exploit banana fibre to the fullest. Banana fibre is an underappreciated or misunderstood waste product in the banana industry. If we can effectively use this fibre, the cost of serval products may come out and it will be boon to the society. Banana fibre is strong, fire-resistant, light, absorbs a lot of moisture, has a low elongation, and is biodegradable. Banana fibre has a lot of potential in the paper industry, particularly for handmade papers. Handling cards, pen stands, filter paper, rope, paper bags, lamp stands, mats, and composite materials employ banana fibre. It's utilized in cars to make underfloor protection panels. Automobile makers employ banana fibre and polypropylene. Interior designers employ banana fibre composite material. Banana fibre paper has a long shelf life.

In order to improve performance, we use matrix and reinforced composite materials. Fiber is mostly used to strengthen. Fiber, natural or synthetic, is usually employed as a reinforcing element (non-biodegradable). Matrix materials include ceramic, polymer, and metallic. Thermoset and thermoplastic (phenolic, polyester, Polycaprolactone, Polyhydroxy butyrate, and epoxy) are two types of polymer matrix (polyethylene, Polypropylene and polyvinyl chloride). A composite is a matrix material reinforced with fibres. A hybrid composite has many fillers and reinforcing elements. A matrix's properties vary depending on the criteria. As a result, understanding mechanical qualities, applications, and manufacture is impossible. This study studied the mechanical qualities, application, and production.

Historical context

- Fiber from bananas

Unlike other natural fibres, banana fibre has several distinct properties. Banana fibre is harvested from a banana tree. Banana fibre, also known as Musa fibre, is one of the world sturdiest natural fibres. The natural fibre is made from the stem of the banana tree and is biodegradable. Banana plant outer sheaths produce thicker, more durable fibres, and the inner sheaths have softer fibres. According to Bilba [1] banana leaves (BL) and the pseudo-stem banana core were investigated as two sections of a banana tree (BC). It was assumed that the existence of more hydrogen in BL fibres was related to the fact that BL fibres had fewer double links as compared to others. Bananas are a tall herbaceous plant (2-16 m) with a pseudo-stem made up of densely overlapping long fibres. According to Samel [2], Banana fiber has strong tensile, flexural, and resistance. After further investigation, it was discovered that the majority of researchers, such as William Jordan [3], Shih, and Yeng-Fong [4] employed pseudo-stem banana fibre.

Banana fibre can be used to dampen the sound of a stone hitting an automobile. The first component quality fibre is banana fibre. Ibrahim [5] claims that banana fibre and banana micro fibrils can be made from lignocellulose waste using alkaline pulping and steam evaporation. William Jordan [3] argues that all lignocellulose fibres are chemically identical. Cellulose, hemicelluloses, and lignin. However, they will be the same for the same plant species. Lignocellulose offers a variety of mechanical characteristics. Transportation, storage, and the extracted fibre's life cycle may all contribute to this. Raw banana fibres mechanically separated from the stem are utilised to improve the qualities of natural banana fibres subjected to chemical surface changes, according to Shih [4]. The banana fibre is first washed in detergent, then treated with NaOH, and last with saline acetone.

Encouragement of natural fibres in composite materials can significantly minimize the greenhouse effect, as we mentioned in various paper [6]. As a result, the goal of our research was to look into the physio-mechanical properties of walnut shell powder (WNP)-with banana fibre (BF) fiber-based epoxy (EP) composites. We discovered that adding walnut powder to the BF/EP composites significantly improved their mechanical properties and wear resistance.

M. Boopalan [6] says banana fibres are non-abrasive, renewable, and can be burned for energy. It is easy to handle and has a lot of calories. It's also cheap, light, and strong. Its eco-friendliness makes it appealing in engineering industries like construction and automobiles. N. Venkateswaran [7] found that adding 50% sisal to a banana/epoxy composite improved mechanical characteristics while decreasing moisture absorption.

- Banana Fiber Reinforce Polymer and Composite

Several researchers recommend adding a modified compatibilizer to the modified polymer to increase Fiber-Polymer binding. M. Ibahim [5] suggested that lignocellulosic fillers are created from banana plant waste and reinforced with polyethylene. Adding melted fibre to the polymer matrix improves adhesion and tensile strength but increasing fibre concentration from a specific limit reduces adhesion and tensile strength.

Factor Influencing the mechanical properties of fiber Reinforced composite (FRCs)

- Type of fiber used: Characterisation

Natural fibre characteristics are mostly determined by their physical properties and chemical organisation, according to Gupta [7]. Processing "pseudo stems of banana plants" yields banana fibre (Musasepientum). The majority of banana fibre is made up of lignin, cellulose, and hemicellulose, earning it the moniker lignocellulosic fibre. As a result of their chemical make-up and structure, composite materials based on reinforced natural fibres offer outstanding mechanical qualities.

Banana fibre reinforced composite having high tensile, flexural, and impact strength. The physical and mechanical properties of banana fibre reinforced biodegradable. Thermoset, and thermoplastic composites are being studied. Fibers are classified as minerals, plants, or animals. Essential characteristics of the banana fiber are given in Table 1, which states that banana fiber contains cellulose and protein in various concentrations. Chemical composition with the moisture content of banana fiber shown in Table 1 and moisture absorb of banana and walnut chart we have shown in Figure 1. In which we shown moisture absorption in Banana fiber and walnut powder composite in different WNP Loading. As per Banana fiber and walnut powder chart it is conform that as we increase the wt% of walnut powder the water absorption also increases maximum water absorption we can see in 15% WNP and minimum absorption at 5% WNP.

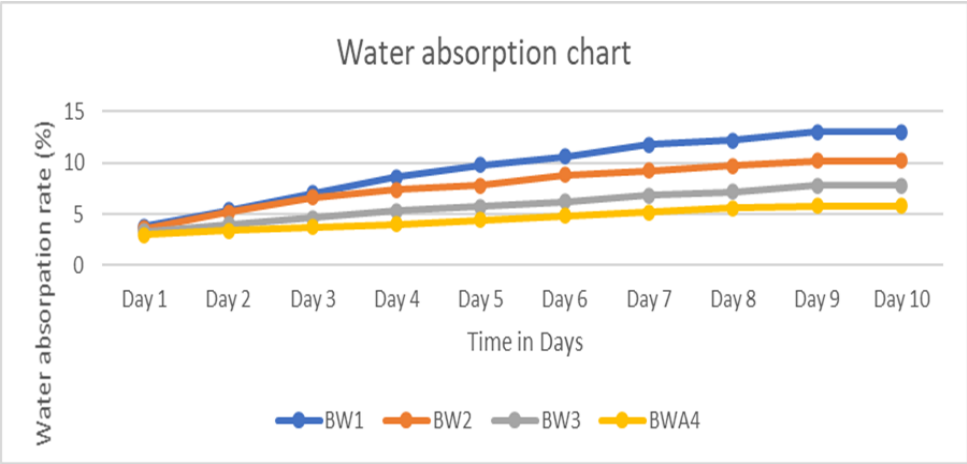

Figure 1. In this BW1-30% B/F and 0% WNP,BW2,BW3,BW4 -5,10,15% WNP with 30 % BF.

Moisture absorption chart of Banana fiber and Walnut powder in different proportion.
Indria, K.N., et al. [8]. Treated reinforced composites (40 wt%) have better thermal stability than untreated fiber-reinforced composites (40 wt%). The researcher, Kiran [9], reported that a banana-pineapple hybrid composite showed distinct weight friction with epoxy resin. It increases flexural strength by increasing fibre weight friction. He also adds that using two natural fibres instead of one increase flexural strength. The mechanical property of banana fibre is very much comparable to other natural/synthetic fibre shown in Table 2.

Table 1. Chemical Composition and Moisture Content of Banana Fiber. *Source: [8,9].*

Cellulose (%)	**Hemi cellulose (%)**	**Lignite (%)**	**Moisture (%)**	**Ash (%)**	**Density (g/cm^2)**
63±1	19±1.2	5±0.5	11±0.1	1.02	1.3±0

Table 2. Comparative Mechanical properties of banana with other natural/synthetic Fiber.
Source: [8–13]

Fiber	**Density g/cm^2**	**Tensile Strength (MPa)**	**Elongation (%)**	**Young modulus (GPa)**	**Specific modulus (Approximate)**
Banana	1.35	500	1.5-9	12	9
Bamboo	0.6-1.1	40-800	2.5-3.7	11-32	25
Coir	1.2	75-220	15-30	4.0-6.0	4
Cotton	1.5-1.6	287-800	3-10	5.5-12.6	6
Sisal	1.33-1.5	63-700	2.0-4	9.0-38.0	17
Jute	1.3-1.49	20-800	3.7-5.9	8-78	30
E Glass	2.5-2.59	2000-3500	1.8-4.8	230-240	29
Nettle	-	223-930	-	1.7	30
Hemp	1.4-1.5	270-900	1-3.5	23.5-90	40
Kenaf	1.4	223-930	1.5-2.7	14.5-53	24

Dhaka [10] focuses on the characterisation of raw banana fibre polyester composites. He mentions that natural fibres include hemp, jute, banana, sisal, kenaf, and others. Natural fibres' lignocellulosic character has helped them gain popularity in recent years. Rathore [11] summarises the value of combining banana and jute fibres in the same natural polymer matrix, since they often impart their own qualities and produce a nice hybrid composite.

- Matrix Type used

Kumar [13] claims matrix is vital in-plane shear. Strengthening of compression and interlaminar joints. Bananas and other natural fibres have been demonstrated to be compatible with thermoplastics and thermosets. Many researchers investigate banana fibre reinforcement with thermosets such as polyester, vinyl ester, epoxy, and phenolic resin. A number of researchers have created unique composites that are both ecological and biomedical, according to Shih [4]. PLA is a biodegradable thermoplastic that can be utilised in biocompatible/bio absorbable medical equipment or industrial packing. Researchers used oil palm wood flour (OPWF) as a wood basis filler for bio-based thermoplastic composites in a recent study, with good results.
After cleaning and chopping the biobas fibre, Shahinur [14] added thermoplastic granules to boost its mechanical characteristics. With chopped and cleaned fibre combined in thermoplastic granules, he noticed that the mechanical properties were quite comparable to injection moulding. Table 3 shows the Impact Strength of Different Thermosets and thermoplastic resin with banana fibre.

Table 3. Comparative mechanical properties of pure thermoset composites and respective Banana reinforced composites. *Source: [4,13–16]*.

Properties	**PP**	**Banana/PP (MPa)**	**Epoxy (MPa)**	**Banana/Epoxy**	**PLA (MPa)**	**Banana/PLA**
TS (MPa)	19.71	11.45-24.16	33.86	114	39.3	78.6
FS	38.82	38-42	118.75	74	39.4	65.4
Impact kg/m^2	19-22			10.439 (Joule)	22.2 (J/M)	17.1 J/M

According to Dhakal [10], matrix is used to secure fibres and transfer weight between them. It also protects the fibres from the elements. Kiran [9] claims that the matrix organises the fibres regularly. The matrix material takes many forms. Ceramic, polymer, or metal. A metal matrix is an alloy reinforced with metal fibres like boron carbon. Examples of polymer matrix composites are PMCs and ceramic matrix composites.

- Separation of Fiber

After drying, most natural fibres, especially banana fibre, must be chopped horizontally to provide strength and variation. According to Sapuan [17], fibre separation is affected by length, temperature, and pressure. R. Karthic [18] used woven and nonwoven banana fibres to generate fibre dispersion in order to examine the length effect. The significance of fibre coarseness and length has been demonstrated.
According to Mishra, [19] Poly(lactic acid) is easily available in pallet form and is frequently used for the production of bio-composites, particularly by melt extruder and injection moulding. Several positive changes in PLA's mechanical and wear characteristics have been recorded and some future recommendations. With the addition of filler, PLA demonstrated a decrease in tensile and flexural strength, which can be changed by using compatibilizers or mixing appropriate biopolymers.

- Fiber orientation

The orientation of the woven jute fibre has a significant impact on the mechanical and thermal properties of composites made with different resins. Unlike natural fibres, banana fibre offers a wide range of lengths. According to Amir [15], optimal mechanical properties are obtained when fibres are parallel and of required length. As Alavuden [20] discovered, woven banana/kenaf hybrid has a higher mechanical strength than individual banana/kenaf fibre. He compares the mechanical properties of random and woven fibres, concluding that weaved fibre beats random orientation.
Ezema [21] found that variation in properties due to fibre orientations was observed

indicating a higher value of properties in the 00-fiber orientation than in 45˚ and 90˚ directions, which is shown in Figure 2 and 3.

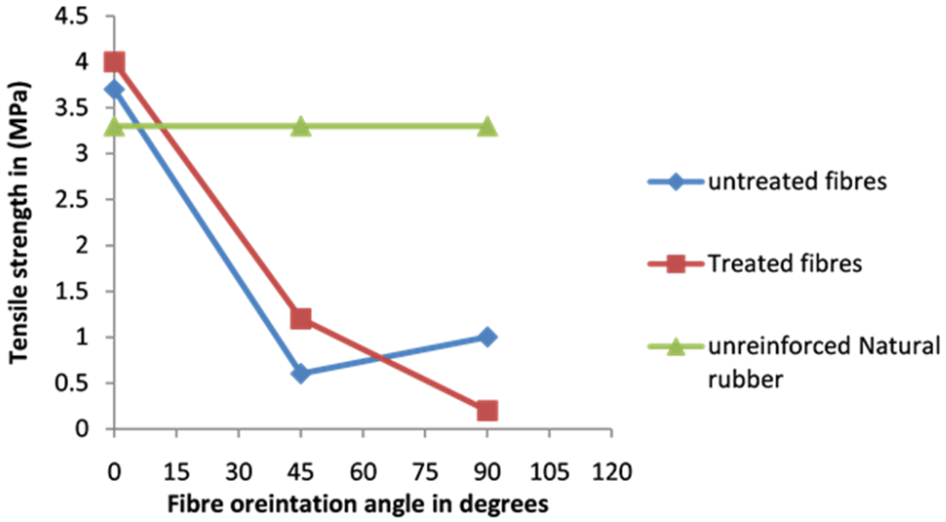

Figure 2. Effect of fibre treatment and orientation on the ultimate tensile strength of banana fibre-NR composite.

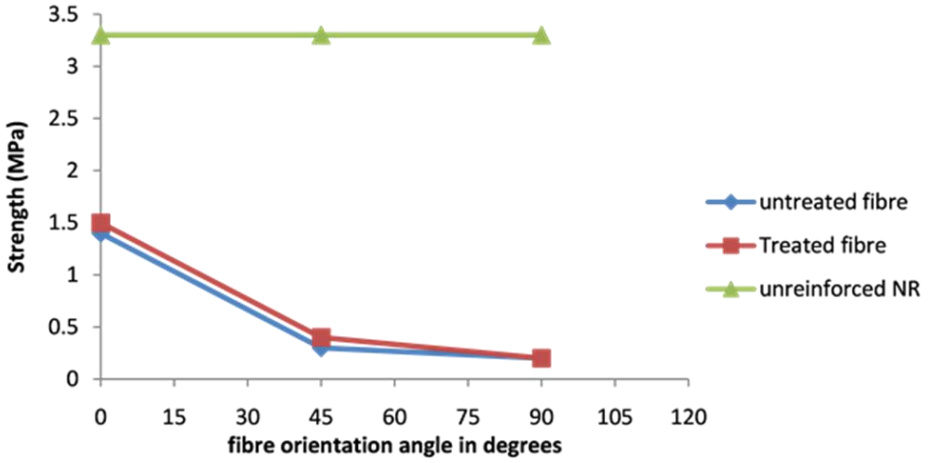

Figure 3. Effect of fibre treatment and orientation on banana fiber-NR composite failure strength.

Chandrasekar et al. [22] analysed the effect of fibre inter-ply orientation on the mechanical and free vibration behaviour of banana fibre reinforced polyester matrix composites. Characterization of 50 ± 2 wt% banana fiber reinforced polymer composites were carried out using cross-ply laminates ([90/0/90] and [0/90/0]), [0/45/0], four-layered angle ply laminate ([90/0]s) and quasi-isotropic laminates ([0/90/45]s, [0/45/90]s,).The study reviled that composite having [0/90/0] laminates showed superior elastic modulus, tensile strength, impact strength and natural frequency. In comparison to other configurations, Quasi-isotropic laminate composites exhibit better flexural properties.

Chavali's [23] research looked at a banana fiber-reinforced composite's tribological and mechanical properties with various orientations. He discovered that strength decreases more rapidly by 41.82 % from 0 to 45 orientation due to higher tensile stress developing in fibres than shear stress, whereas strength decreases by 14.21 % from 45 to 90 orientation.

- Composite Void and porosity

Many volatiles and air bubbles become trapped in composites during manufacture and remain as tiny voids. P. Deepak [24] recommends rolling over the mould when producing compost to reduce voids induced by the exothermic reaction of hardener and resin. Rathore [11] claims that nanocomposite has successfully minimized voids by using nanofiber. According to Amir [15], PP/banana composite has the lowest

tensile strength due to void. Load transfer between fibres and matrix is reduced due to the composite's weakness. Biba [1] studies the natural fibre of banana and coconut trees chemically and texturally. He discovered that by calculating the temperature of pyrolysis of fibre before it changes in the cement matrix, we may predict the behaviour of composites in the presence of large porosity.

Banana Fiber Reinforced Thermoset Polymer Composite

The combination of banana fibre with a thermoset polymer matrix increases mechanical properties. Many researchers are investigating banana fibre reinforcement with thermosets. Table 3: Impact strength of different thermostats (IS or ST). Rathore [11] elaborates on the production of natural fibre reinforced thermosets. He also compounds sheet moulding and Thermoset compression moulding with resin.

- Resin and Fiber

When fibre and resin meet. By increasing the fibre's strength, toughness, and rigidity, it increases its load-bearing capability. We use technologies like twin vacuum, injection pressure moulding, and injection wall to raise the pressure gradient. Bhoopthi [25] used banana, hemp, and glass fibre as reinforcement materials in three different laminated hybrids. The experiment revealed that a banana-hemp-glass hybrid with epoxy resin has excellent mechanical properties and can be used as a substitute for synthetic fibre reinforcing material.

- Fiber with sheet moulding

Fiber is produced to sheet and laminate by hand, then thermal, such resin, is combined to enhance the chemical reaction, increasing temperature resistance.

- Fiber Compression Moulding

Liu [26] observed that banana fibre reinforced well with various thermosetting resins such as unsaturated polyester. Using thermoset to diminish banana fibre loading also affects the banana's water absorption characteristics at ambient proportions. Ravi Bhatnagar [27] asserts that banana fibre composite is perfect for thermoset for transportation and the vehicle industry. There was a lot of research on how natural fibres like banana and coconut functioned with thermoplastics.

Banana Fiber Reinforced Thermoplastic Polymer composite

A number of researchers have created unique composites that are both ecological and biomedical, according to Shih [4]. PLA is a biodegradable thermoplastic that can be utilized in biocompatible/bioabsorbable medical equipment or industrial packing. Researchers used Oil palm wood flour (OPWF) as a wood basis filler for bio-based thermoplastic composites in a recent study, with good results. After cleaning and chopping the biobas fibre, Shahinur [14] added thermoplastic granules to boost its mechanical characteristics. With chopped and cleaned fibre combined in thermoplastic granules, he noticed that the mechanical properties were quite comparable to injection moulding.

Biodegradable Polymer Composite Reinforced with Banana Fibers

According to Shih [4], biodegradable polymers are becoming more popular in material science. Poly(lactic acid), which has a high modulus, is one of these biodegradables. PLA is a high-strength thermoplastic polymer which is perfect for medical and industrial packaging. However, its low thermal deformation temperature and high cost limit its use. Combining BP (Biopolymer) with banana fibre produces a natural green composite with improved mechanical and thermal qualities while lowering costs.

Impact strength of banana fibre reinforced polymer composite

Composites containing molybdenum disulphate, such as banana fibre, have lower impact strength and thus lower toughness, according to Deepak [24]. According to Rathore [11], some researchers have observed that bio nanocomposite with catalyst has a significant impact strength. Liu [23] analysed the banana fibre composite made of HDPE/Nylon-6 (80/20) was made in two stages by altering SEBS-g-MA and PE-g-MA. SEBS-g.MA was found to enhance the reinforcing effect and impact. With a 5 mm thick banana fibre matrix, hardener, and catalyst, Sarub Dhaka [10] provides the highest impact strength with tensile. Alavudeen [20] studied the tensile, impact, and flexural strength of woven hybrid composite of Kenaf/Banana fibres. [16]. According to Ramesh, glass epoxy has a far higher impact strength than banana epoxy when mixed with glass fibre.

Limitation of Natural Fiber:

In spite of the many benefits of natural fibers in NFPCs, there are some disadvantages, such as excessive water absorption and poor thermal properties. These lignocellulosic composite materials also exhibit heat conductivity and acoustic insulation properties, which have been less explored. In order to make these materials more widely available and safer, future research into the characteristics of various natural fibres will be necessary. According to Raghavendra, a natural fibre's ability to reinforce depends on cellulose's composition and crystallinity [28].

- Fiber treatment

All-natural fibres can be treated using chemicals. Treatments include NaOH, saline, dicumyl peroxide in acetone (peroxide therapy), and potassium paramagnet in acetone (paramagnet treatment). Mechanical Properties of Bio-based polymer composite shown in Table 4.

Bhupathi [25] showed that alkali, salt, and acetyl treatments work well on natural fibre. After heat treatment, Indira [8] revealed that there is a change in surface topology between untreated and treated banana fibres. As a result, deterioration, disintegration, and activation of energy demand more energy after treatment.

Asim Shahzad [29] used advanced chemical technologies, such as chemical reagents, to lower the hydrophilic inclination of fibres and therefore increase matrix compatibility.

Chemical treatment of banana fibre is used to improve adhesion between banana fibre and polymer matrix. sodium lauryl sulphate, Alkali, and maleic anhydride are all common chemical treatments. The characteristics of banana fibre reinforced polymer composites improved with increasing banana fibre content, according to the literature. Chemical treatment of banana fibre improves the characteristics of the resulting polymer composites in general [30].

Peroxide treatment is an advanced way for reducing fibre moisture absorption. To obtain the required effects and increase thermal stability, hydroxyl groups react with free peroxide radicals react in this approach [31].

Alkali and SLS (Sodium lauryl sulphate) treatments can also be used to improve banana fibre mechanical properties. SLS treatment outperforms alkali for enhancing mechanical properties and surface modification. SLS has stronger tensile, flexural, and impact strength than Alkali.

Table 4. Mechanical Properties of Bio based polymer composite. *Source: [11,12,14].*

Bio composite	**Tensile strength (MPa)**	**Flexural (MPa)**	**Impact kg/m²**	**Hardness Rockwell (L)**	**Water absorption (%)**
Jute	320-800		25-85	78-97	0.7-1.26
Treated jute			18-24	77-87	0.73-1.22
Coir	95-230		35-60	80-90	0.3-1.72
Treated coir			40-60	90-105	0.3-0.7
Banana	500		1.2-1.8	60-66	1.5-3.0
Treated banana			0.9-1.5	66-72	1.0-2.5
Coir-PP	22-27	46.50			
Treated coir-PP	27-30	53-60			
Jute-PP	17-34	20-32			
Treated jute-PP	15-51	15-58			
Banana-PP	11-22	38-42			
Treated Banana-PP	23-24	36-39			

- Additives or Filler

The fundamental distinction between various fillers and additives and treatment is that fillers or additives mix with the matrix to strengthen mechanical qualities, whereas fillers receive treatment. A modest amount of resin is blended with filler or additives. The majority of fillers improve the mechanical properties of composites while also controlling the viscosity and producing a smooth finish. Elanchezhain [32] stated that adding filler (stiff coir

and jute) to a soft polypropylene matrix improves the flexural modulus. Sweety Shahinur [14] explains how composites are made up of a matrix and a reinforced material and how adding filler can increase performance. Bhatnager [27] discovered in his review that when red mud is added to the filler, it provides maximum mechanical strength as compared to pure BFRPCs (BFRPCs percentage 50 percent)
Filler is well-explained by Pothan [33]. He refers to Nelasion because natural fibre can be employed in automotive structures. According to this, the law of mixture can be used to predict the mechanical properties of composites. He gives one formula for analysing the damping property of composites, which is also useful for studying the damping property of composites.

$$\tan \delta_c = \tan \delta_m (1 - \phi_f) \quad (1)$$

tan δc - represents composition damping, which is a matrix proportional contribution to its relative content
tan δ m - represents the matrix damping value, and ϕf represents the friction volume of the filler.

- Hybridization

Nagaraja, K. C. [34] created a hybrid composite laminate and studied the reinforcement hybridization effect. The statistics show that 10% MRP increased the mechanical properties significantly. This decreases E-Glass fibre content in composites. Due to its exceptional mechanical properties and low cost, this composite was recommended for many technical applications.
Banana fibre is appropriate for replacing current fibres, according to Subagyo [35]. Banana pseudo steam fibres are removed using fibre extractors. The raw material is cheap and widely available.
Ramesh Kumar [36] developed hybrid composites made of kenaf, glass, banana, and graphene filaments, which are widely used in polymeric networks in automobiles, space vehicles, and aviation development. In this study, nanohybrid composite laminates with varying weight percentages nanofiller of graphene and reinforcing materials such as banana, kenaf, and glass fiber were made with epoxy resin and different weight percentages of graphene as nanofiller. The results reveal that including graphene into epoxy resin enhances the mechanical properties of nanohybrid composites and that kenaf/glass fiber hybrid nanocomposites outperform banana/glass fiber hybrid nanocomposites.
Temesgen [37] investigates the mechanical characteristics of hybrid composite materials reinforced with false banana/glass fibres at different orientations of hybrid (glass and false banana) fibres and fibre volume fractions. The results reveal that both fibre orientation and volume fraction substantially impact the mechanical characteristics of the artificial banana/glass fibre hybrid composite.
Ravi Y.V. [38] creates the composite hybrid helmet with natural hemp and banana fibres and polyester resin as the matrix material, utilising a traditional hand lay-up technique. The helmets are prepared before being put to the test. According to the tests, natural fibres have good strength and impact resistance and are the best alternatives to synthetic fibres, which are extensively employed in the helmet manufacturing industry.
The influence of fibre orientation on the abrasive wear behaviour of banana fibre reinforced Chavali and Taru [39] studied epoxy composites. The wear test was carried out using an ASTM-approved pin-on-disk tribometer. Low wear was observed at 00 fibre orientation, increasing to 900 fibre orientation for 20 N and 50 N at 200 rpm. Wear is related to the contact area; therefore, fibres are more wear-resistant than resin. At 00 fibre orientation, there was less contact between the fibre and the disc, resulting in minimal abrasive wear. In composites with 900 fibre orientation, the contact area between fibre and disc was greater.

- Impacts in Polymeric Composites

The results of the Mahesh, D. [40], experiment that, the 50 percent banana fibre and 50 percent polypropylene composite materials can bear higher loads than the other combinations and can be utilised as an alternative to traditional fiber-reinforced polymer composites.
Neher employed [41] obsolete high-density polyethylene (HDPE) as the polymer matrix and banana fibre as the reinforcement material in this investigation and he discovered that bulk density and tensile strength grew by wt.% while flexural strength declined. Flexural strength increased for 5 wt.% BF-HDPE composites at first, but then decreased for other higher compositions.
Samal [2] created banana fibre reinforced polypropylene (BSFRP) composites as well as banana-glass fibre reinforced polypropylene (BSGRP) hybrid composites. He claims that at 30 wt. percent fibre loading, which

is regarded as the critical fibre loading, the highest improvement in polymer characteristics is observed. It is also mentioned by Powała [42], polymer can be utilised to increase mechanical qualities. Many scientists are attempting to enhance the properties such as flexural strength, compressive strength, and water resistance. Certainly Polymers can be used to change the cement matrix.

Banana Fibre's Use in Automobiles and Industries

Incorporating natural fibres into a polymer matrix attracted worldwide attention to the importance of environmental consciousness. According to Jordan [4], natural fibre reinforcement is commonly used in engineering applications. Compared to synthetic fibre, Madhukiran [9] thinks natural composite is a great material for lightweight cars.

On the other hand, Sushant [2] cites Hang, who has thorough information on the usage of natural fibre in vehicle structures and has found natural fibre superior to other materials. Boopalan [6] describes natural fibres as non-abrasive, renewable, and energy-recovery composites. They are easy to handle and high in calories. Low-density natural fibre has great mechanical properties. Synthetic fibre displaced cellulose fibre in the 1970s and 1980s, according to Venkateshwarn [7]. Shahinur [14] quotes Mohammed et al. who stated that natural fibre may replace asbestos in automobile interiors and engineering applications. As seen in the table 5, polymer composite is excellent for autos.

Table 5. Compared to traditional vehicle material composite offer.

Better Internal Damping Leads directly to reduce noise and vibration	Reduced tooling cost Composite tooling cost is only 40% of steel stamping tooling cost
Substantial weight reduction FRP composite are typically 25-35% lighter than steel parts of equal strength	
Unparalleled damage resistance Damage resistance of composite is far superior to that of aluminium and steel panels	Unrivalled corrosion resistance Few materials Offer better corrosion resistance than FRP composite in any application automotive or otherwise
Lowered manufacturing complexity Fewer parts required for a finished assembly cuts manufacturing cost and often speeds run-up to design completion and model introduction.	Improve Design flexibility Moulding offers shape complexity, geometry details, and a depth-of-draw range unavailable with metal stamping, in some case, a part just cannot be manufactured out of other materials.

Application and Future scope

In recent years, it has been used more as a reinforcing material, particularly in the plastics industry, increasing its cost and damaging the environment. So we want renewable and biodegradable. Natural fibre can also be used in other automobile parts. It is based on biodegradability, low cost, lightweight, and high rigidity.

It is possible and convenient to use Jute fibres instead of made fibre, resulting in increased cost-efficiency. Jute fibre was introduced as reinforcement in thermoplastic and thermoset polymer-based composites and has found extensive transportation applications (automobile and railway coach interiors, boat, etc.). The automotive sector, in particular, plays a critical role in this subject. Bulletproof panels were created using natural fibre reinforced composites and epoxy as a matrix. Jute fibres can also be employed in these prototype bulletproof panels were thought to be lighter and less expensive than standard bulletproof panels. Moreover, jute fibers and other natural fibres are also finding their uses in prosthetic applications.

Impact

The current review focuses on banana fiber composites' mechanical and physical properties and their chemical makeup. When compared to other natural fibers, banana fibers have exceptional properties. With the help of composite technology, it is feasible to use and apply lower-cost commodities in high-performance appliances. They are beneficial in several disciplines of engineering, high-performance applications such as leisure and sporting products, shipping industries, Aerospace, and so on, since they combine the useful features of two different materials, lower manufacturing costs, versatility, and so on.

Conclusion

We must stop manufacturing materials that last forever, such as many plastics, in order to protect our environment. Accepting rapid degradation as a result of persistent renewal, as in nature, is not an option. Industry, particularly the automobile industry, which uses a lot of bulk materials, would prefer a midway house of materials that last a long time yet disintegrate back into the environment when they're no longer needed. Reinforced polymers based on natural, primarily plant-derived chemicals show promise in this regard and may prove to be one of the century's material revolutions. In this review , we have gone through the mechanical properties of banana fibres and factors affecting direct characteristics such as fibre length, rebounding, interfacial adhesion, and morphological changes on fibre surfaces. Add more results/outcome statements related to banana fibre.

Conflict of interest

There are no conflicts to declare.

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SUSTAINABILITY AND SECURITY OF PUBLIC BUDGET OF THE VISEGRAD GROUP COUNTRIES

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Abstract
The article examines the theoretical principles of studying sustainability and security of public budget of the Visegrad Group countries and determines that indicators of the normal functioning of the economy and ensuring a decent social standard of living of the population are reaching the limits of relevant indicators, some of which are approved by international standards. At the same time, the authors identified the absence of a single system of macrofinancial indicators of sustainability and security of public budget proposing to create it, including twelve ratios reflecting levels of debt security, deficit load on the economy, debt load on the population, budgetary independence, efficiency, population well-being, productivity, economic efficiency, as well as the effectiveness of financial support for health and education, elasticity of income and expenditure from the change in GDP of the Visegrad countries.
Analytical calculations of the above-mentioned macro indicators in the dynamics made it possible to draw qualitative conclusions on compliance with the sustainability and security of public budget of the Visegrad Group countries, identify possible threats to national economies and prevent the consequences in case of non-compliance with standards. Based on the results of correlation-regression analysis, the authors determined the indicators that have the greatest impact on the resultant factor-the ratio of the level of deficit load on the economy of the investigated countries. It made it possible to analyze the real situation in the economy, to determine the level of sustainability and security of public budget and to give the necessary suggestions and recommendations.

Keywords
sustainability and security of public budget; the Visegrad group countries; economic development; macroeconomic analysis.

Introduction

Social - economic development, its key trends and the impact factors in the Visurged Group countries is the object of high academic interest because of many reasons. Being a former part of socialist area, these countries, (Czech Republic, Slovakia, Poland and Hungary) managed to implement numerous reforms, particularly, economic, medical, educational and territorial, to restore the market economy and achieve the substantial level of social-economic growth and regional development. Thus, their expertise and the achievements in different fields of economy and finance should be precisely examined and analyzed. Different issues of economic and social development

in the V4 countries have been analyzed by a number of scientists, particularly, well-being state Tendera-Właszczuk et al. [1], Nováková et al. [2], institutional and environmental conditions Koziuk et al., public finance Buriachenko et al. [3], quality of life and living conditions Nováková et al. [2], monetary integration Lyzunyzun [4].

Meanwhile, such a crucial issue as a sustainability and security of public budget in Vysegrad countries were not examined to the full extent. Nevertheless, it influences many economic and social aspects in a country and is believed to be one of the vital conditions of regional sustainable development and population needs satisfaction.

The aim of this research is to propose the framework of indicators which provide the comprehensive and clear evaluation of sustainability of public budget, to assess the current state of sustainability of public budget in the V4 countries and to define the main factors influencing budget deficit in each V4 country. To achieve these objective statistical methods of regression analyses were applied [5].

Since the term “sustainability” can be considered in different ways both quantitative and qualitative [3,6], it will be used for the objective of this research based on the Cambridge Dictionary definition, namely as “the quality of being strong, and healthy or unlikely to break or fail” [7,8]. This budgetary situation can be achieved if budgetary expenditures are less than a total revenue while the share of non-utilized revenues reaches 60-70% of the total municipal revenue accumulated on its territory. So, sustainability of public budget can be considered under two aspects. Firstly, as an ability of local bodies to accumulate this amount of revenue which covers all the local expenditures and provides balanced budget. Secondly, as an ability of local authorities to provide local population with sufficient social services for the satisfaction of its needs [9,10].

Manuscript "Suggestions for a New Set of Fiscal Indicators" [7] is devoted to the substantiation of four groups of fiscal indicators designed to answer the question: what in the tax system is caused by changes in the economic environment, and what is due to government policy?, is it possible to support the current course of fiscal policy through tax or expenditure adjustments?, what is the impact of fiscal policy on inflation?, which macroeconomic impact makes fiscal policy through deficit and debt financing?!

According to this, sustainability of public budget should be understood as a budgetary situation which provides healthy functioning of a public body, execution of its powers based on the full and opportune budget expenditures, including servicing external and domestic debt [5,11]. Correspondingly, sustainability of public budget of a region presumes the provision of own resources, relies on the structure of financial resources for a municipal development and its dependence on the external funding. Thus, an assessment of sustainability of public budget is to be executed through a framework of indicators that can characterize the structure of financial resources in a region, their amount and stability, as well as the efficiency of corresponding expenditures aimed at a regional sustainable development [12].

The key characteristics used to evaluate sustainability of public budget include first of all the indicators of a budget independence (a budget ability to collect necessary financial resources mostly through tax system self-sufficiently), dependency on transfers and external financing, soundness, tax autonomy and ability, share of equalization transfer in the whole amount of transfers, income/outcome transfers ratio, which characterize mostly the revenue part of sustainability of local budget [13,14]. Some researchers added also the ratios of debt load to these indicators (the ratios of debt load - indicators of a debt structure, a debt servicing, share of account payable in the whole revenues) [15,16] and a budget efficiency ratio (a budget provision of the population, deficit level ratio, a budgetary performance, revenue stability indicator).

Bojarska et al. [17] consider that sustainable development is a global mega-trend in all spheres of life and priority for people all around the world. The implementation of the seventeen tasks of the Concept of "Sustainable Development Goals", which must be completed by 2030, provides the development of an appropriate system of sustainability indicators based on the latest scientific research.

The issues of digital transformation of the sustainable development system in the EU countries, including Visegrad Group, are studying in the works of Esses et al. [18] and Matthess et al. [19]. Thus, researchers emphasize that the evolution of digital transformation poses actual challenges and provides many new opportunities, as well as unique solutions of individual issues for both economic sectors and regions. Authors consider the need of studying the relationship between digital transformation and sustainability in the countries of Visegrad Group.

An important is to accept the offers of Khanova et al. [20] to use certain indicators of sustainable development of the EU countries and Ukraine. The presented methodology of calculating the ratio of economic, social and environmental efficiency formed the basis of system of indicators of sustainability and security of public budget.

Reflecting the state of a local budget, its revenues, independence, reliance on a central budget and inter-budgetary transfers the latest above-mentioned approaches estimate only limited number of expenditures, namely-dept - servicing and gross expenses p.c, [21], In the meantime, it is social services financing and delivery to population as well as regional long-term development should be considered as the main goals of regional budgeting and

its sustainability achievement. From this point of view, the current research proposes to use additional indicators in a sustainability of public budget evaluation which characterize such spheres of public services and budgetary expenditures as education and healthcare system, namely-the indicator of healthcare system financing and education system financing. Besides, two new indicators-elasticity of budget revenues and expenditures-are proposed to use in a sustainability of public budget assessment. Both of them are calculated as the ratios of increment rates of budget revenues/expenditures and GDP and reflect the change of revenues/expenditures in case of 1% change of GDP.

The dynamics of indicators of stability and security of public budget of the Visegrad Group countries is influenced by many factors. Economic growth factors that allow the reviewed countries to develop are GDP, GNI, revenues and taxes of the public budget. They impact on the studied indicators positively, provide an opportunity to improve the standard and quality of life. On the contrary, negative factors (inflation, deficit, public debt, etc.) can have a positive effect only if the thresholds expressed in terms of indicators of stability and security of public budget are met. If the maximum allowable values are exceeded or insufficient, these macroeconomic indicators have a negative impact on the economy of the Visegrad Group countries and may lead to the state's failure to perform its functions, which may bring countries closer to crisis or default.

At the same time some of the indicators being used by other researches were excluded in this research because of their limited efficiency for its goal or overlapping other similar indicators and results overload [16].

Based on this, the assessment of sustainability of public budget in the V4 countries is proposed to execute within the framework of 12 indicators which reflects a budget efficiency, solidity, strength and wealth. This indicators framework will allow to measure a sustainability of public budget in these countries and formulate the qualitative interpretation of the results achieved (Table 1).

Table 1. Sustainability and security of public budget indicators. *Source: Public finances in Euro Area Member States selected indicators.*

No.	**Indicators**	**Recommended limit**
1	A debt security, % GDP	up to 60%
2	A budget deficit, % GDP	up to 3%
3	A debt load p.c.	up to 300 USD p.c.
4	Budgetary independence (a share of budget revenues in expenditures)	over 80%
5	Budgetary performance (a share of budget revenues p.c.)	↑
6	A budget provision (a share of budget expenditures p.c.)	↑
7	Budgetary financial performance	↑
8	A budget economic efficiency	↑
9	Healthcare financing share in GDP	over 4%
10	Education financing share in GDP	over 8,3%
11	Revenue elasticity depending on GDP changes	↑
12	Expenditure’s elasticity depending on GDP changes	↑

Methods

The macrofinancial indicators of the Visegrad Group countries were collected, processed and analyzed and the methods of economic and statistical analysis were applied for the analytical part of the study. Based on the analysis of relative values, the ratios of stability and security of public budget were calculated and compared with the recommended marginal values of these indicators.

By means of dynamics analysis the values of the investigated indicators were compared over time. Correlation analysis allowed to identify among the set of factors those that mostly influence the effective feature - the value of deficit load on the economy. It should be noted that when the correlation analysis showed an insignificant (low) level of relationship between investigated indicators, such a relationship was not researched in the regression analysis. The regression analysis showed a quantitative measurement of the impact of each factor on the outcome. The values of indicators obtained were summarized and tabulated to demonstrate and formulate conclusions, suggestions and recommendations.

This research is performed using the data, necessary for the calculation of the above-defined indicators of a sustainability of public budget from the V4 countries - Poland, Czech Republic, Slovakia and Hungary (Figures 1-7).

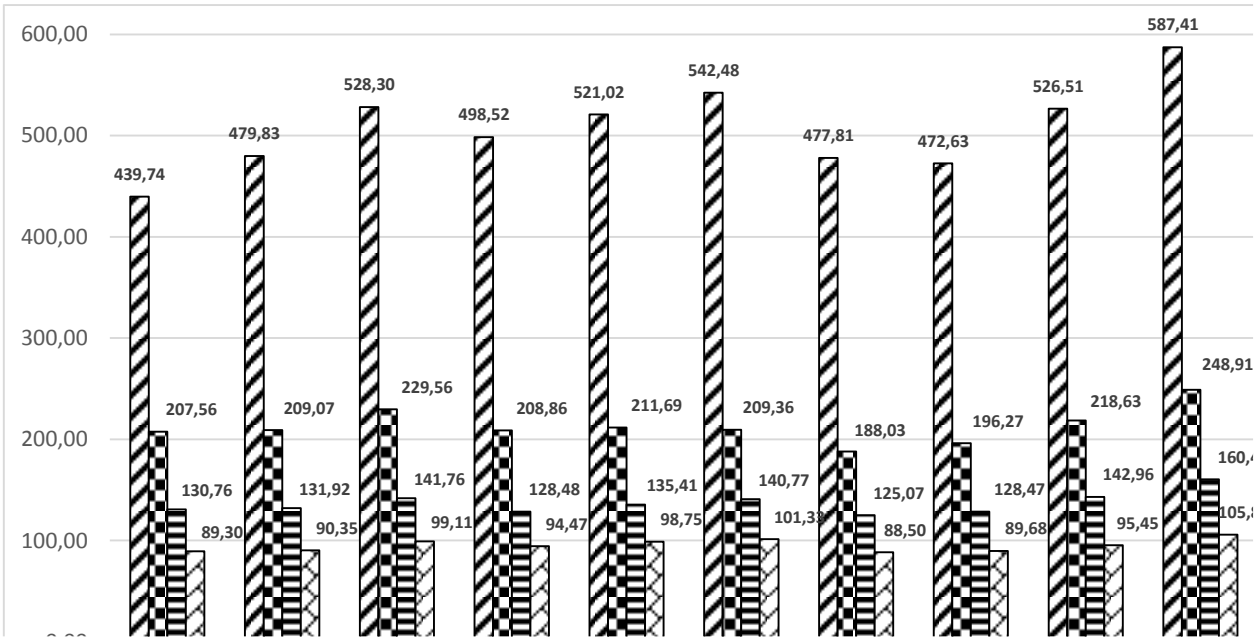

Figure 1. Initial macrofinancial indicators GDP of the Visegrad Group countries, billon USD.
Source: own processing based on data from Visegrad Group.

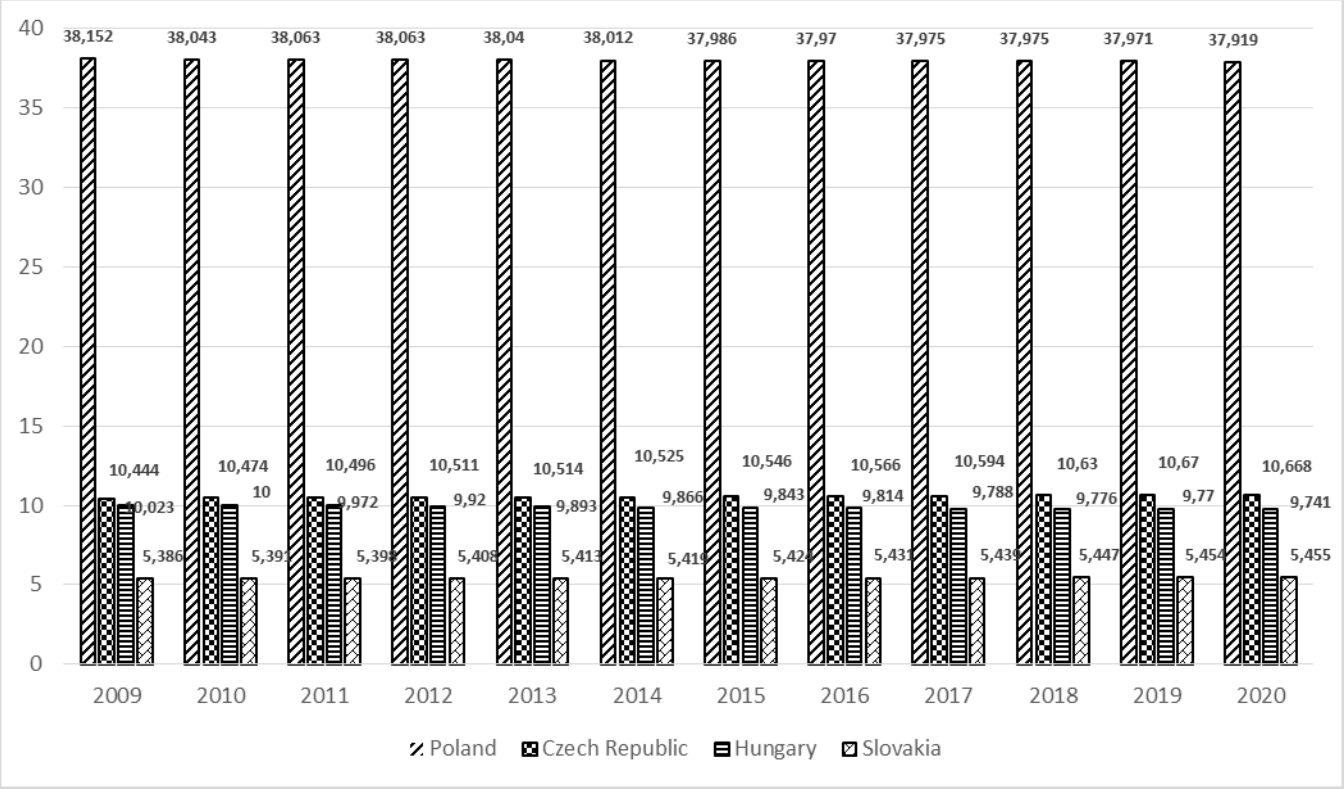

Figure 2. Initial indicators population (P) of the Visegrad Group countries, million people.
Source: own processing based on data from Visegrad Group.

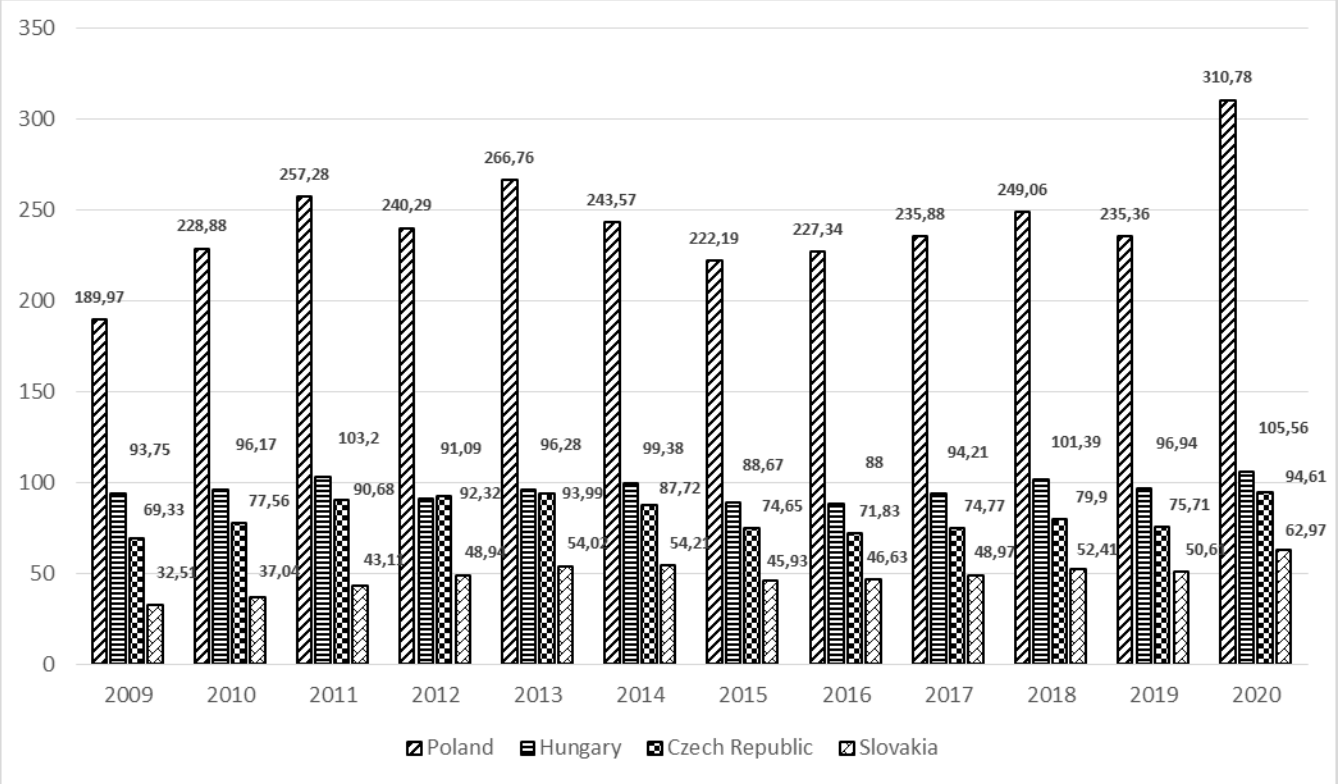

Figure 3. Initial indicators of the total public debt (PD) of the Visegrad Group countries, billion dollars.
Source: own processing based on data from Visegrad Group.

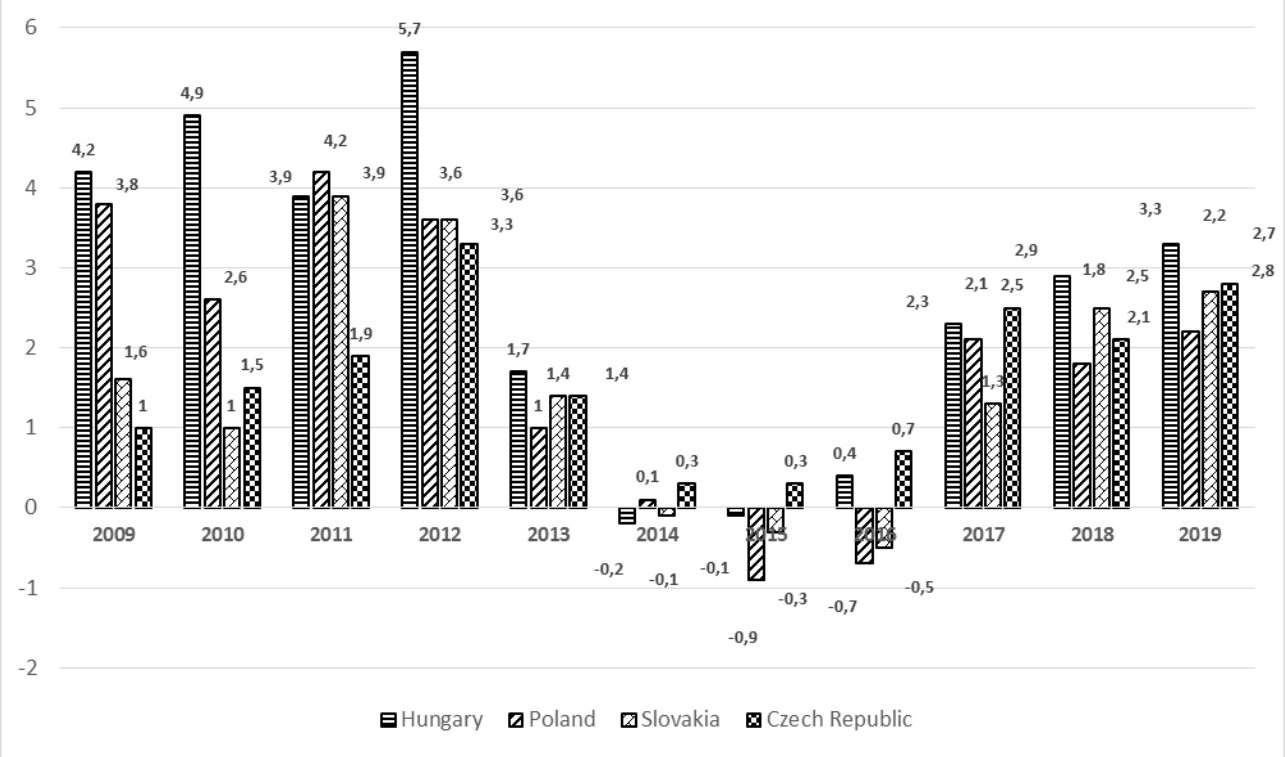

Figure 4. Initial indicators of inflation index (I.) of the Visegrad Group countries,%.
Source: own processing based on data from Visegrad Group.

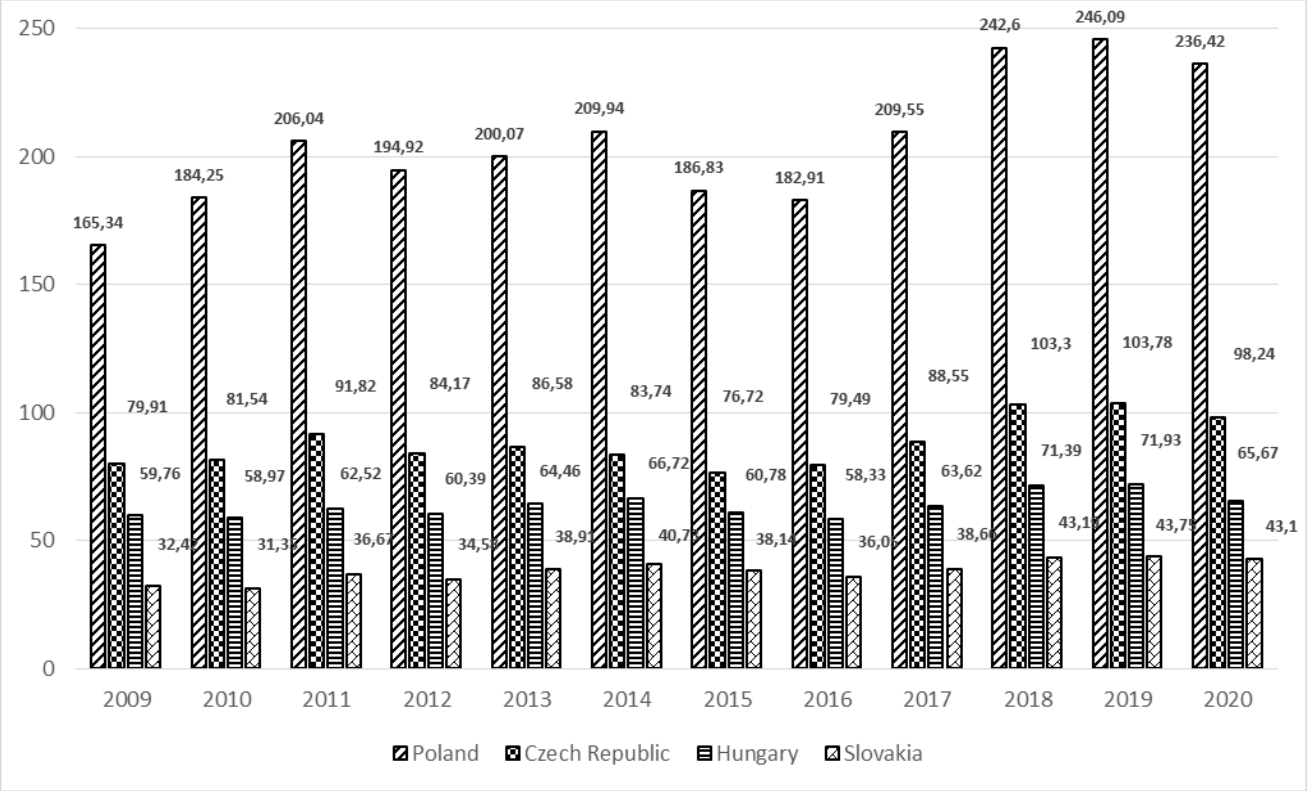

Figure 5. Initial indicators of Income (In.) of the Visegrad Group countries, billion USD.
Source: own processing based on data from Visegrad Group.

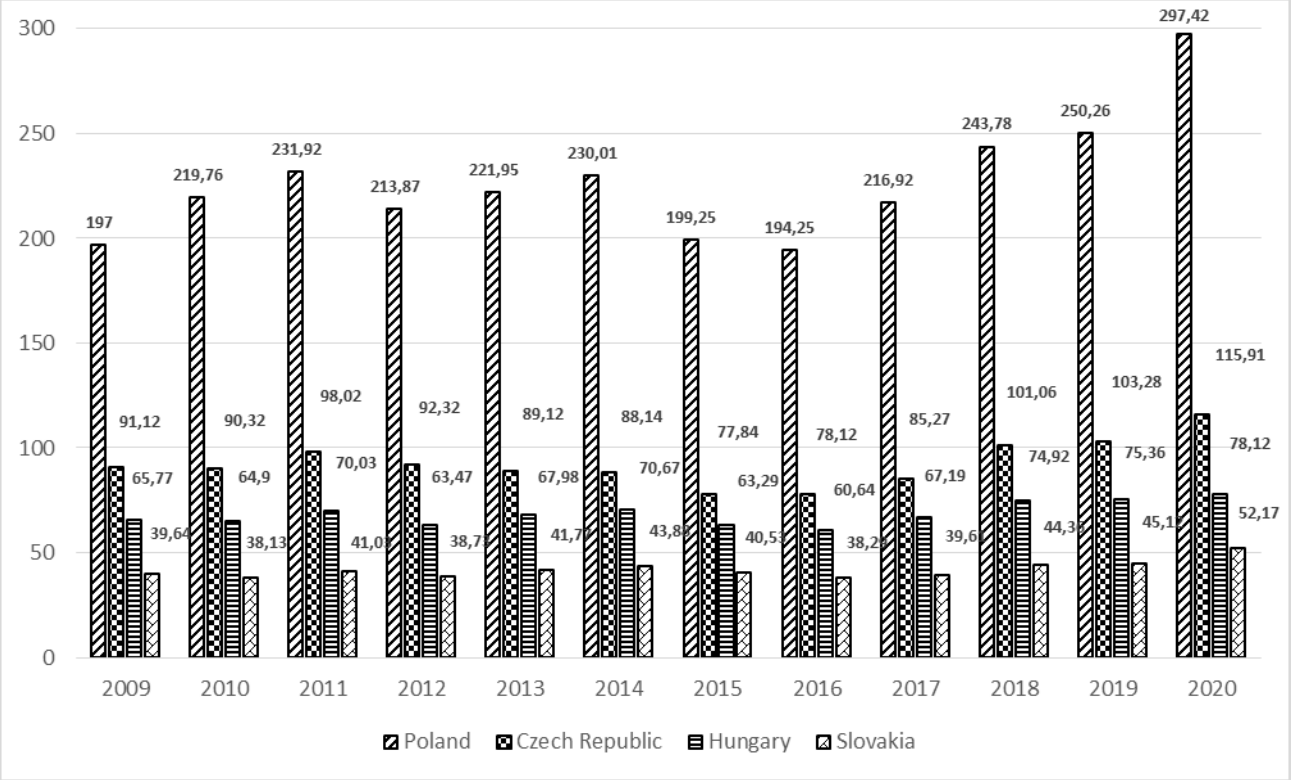

Figure 6. Initial indicators of Expenses (Exp.) of the Visegrad Group countries, billion USD.
Source: own processing based on data from Visegrad Group.

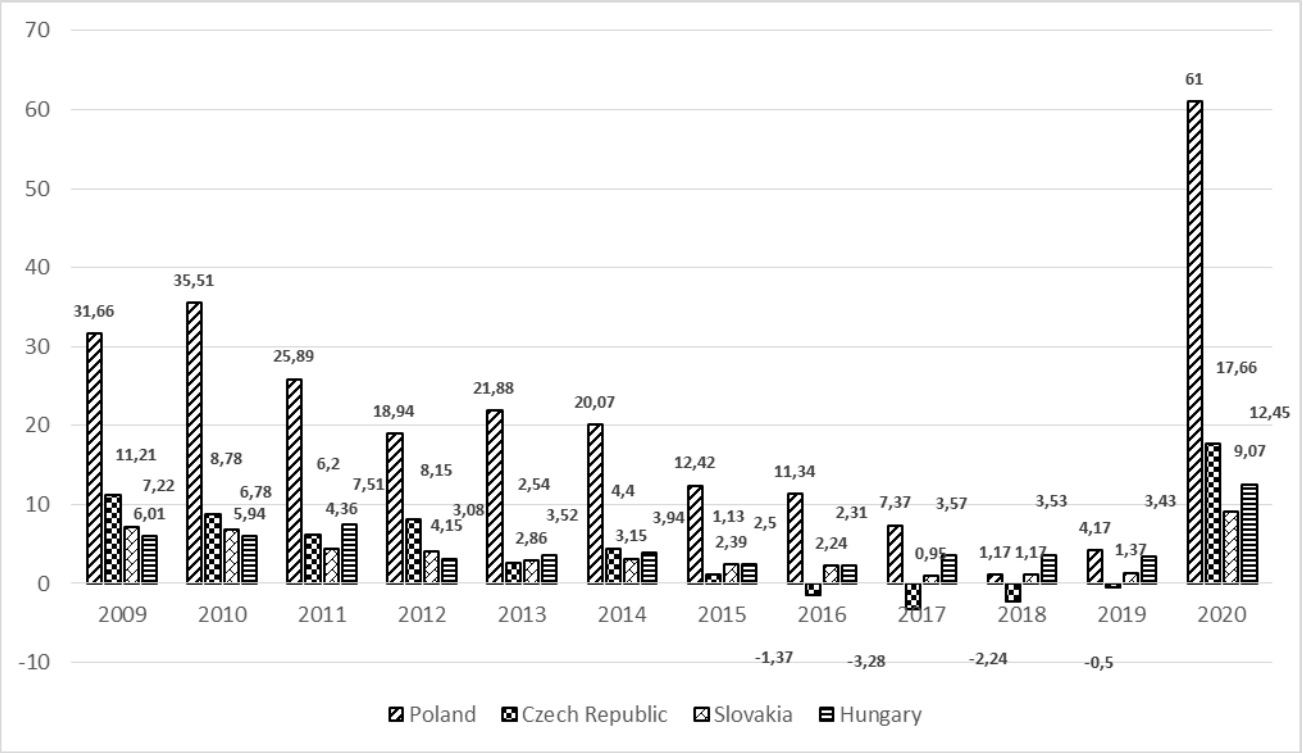

Figure 7. Initial indicators of Deficit (Def.)/Profit (Prof.) of the Visegrad Group countries, billion USD.
Source: own processing based on data from Visegrad Group.

In order to analyze the changes of the factors influencing a sustainability of public budget the research covers the period of 2009-2020. The data was obtained from the financial statements of the V4 countries (Data V4 countries, 2020).

Results and discussion

Sustainability of public budget.

Security of public budget is a component of national security, showing the optimization of the relationship between perceived economic threats and budgetary resources to counter these threats, reflects the state of the economy, which provides sustainable economic growth, effective satisfaction of economic needs, state control over the movement and use of national resources, protection of the country's economic interests at the national and international levels, including territorial unity, state sovereignty, inviolability and budgetary independence.

Security of public budget is one of the main indicators of assessing the effectiveness of public policy to strengthen the social sphere, the state influence on the development of macroeconomic processes such as economic growth, defense, acceleration of scientific and technological progress, radical re-equipment of material and technical base of production, development innovation processes, reducing unemployment, increasing employment etc.

Sustainability of public budget is an economic category that determines the state of the public budget, which ensures the normal functioning of the public authority, the implementation of all its powers based on full and timely financing of budget expenditures, including repayment of external and internal debt. Reflects the state of the totality of monetary funds, in which the state and regions are constantly evolving, ensuring their financial security of the public budget in terms of additional levels of risk.

Indicators of the stability of the state budget of the Visegrad Group.

Calculations of the main indicators of sustainability of public budget and safety are given in Tables 2-13. As the calculations of the debt security ratios of the countries of the Visegrad Group have proved, the excess of debt security norms is observed only in Hungary during the investigated period and in Slovakia in 2020. This situation may cause problems for the country's solvency to meet its payment obligations in full: it indicates inefficient use of internal and external borrowing, inadequate control over this process, cyclical downturns in the economy, high dependence

on imports, and a decline in production. In spite of the low debt security level, it should be noted that until 2019 the situation in Hungary has improved due to the fact that GDP growth rates significantly exceed the national debt growth rate (as proved by the overall decrease of the investigated indicator from 71.70% in 2009 to 59.30% in 2019). Efficient management decisions, namely clear selection of the national debt policy strategy, optimization of the national debt structure and improvement of the level of socio-economic development, are required to ensure the marginal norms of this debt indicator.

In other countries of the Visegrad Group (Czech Republic and Poland), debt security indicators were normal during 2009-2020, in Slovakia - 2009-2019. Their negative trend of growth during 2009-2013 (Czech Republic and Slovakia) and 2009-2012 (Poland) changed for a positive trend of decrease in 2014-2019. These countries manage to serve the national debt through the redistribution of domestic consumer goods to export goods. This means that these countries completely meet their payment obligations and have no solvency problems, which is one of the important indicators of sustainability and security of public budget (Table 2).

Table 2. Dynamics of coefficients of the level of debt security of the Visegrad Group countries.
Source: own processing based on data from Visegrad Group.

Years	**Czech Republic**			**Slovakia**			**Poland**			**Hungary**		
	PD.	GDP	PD./GDP	PD.	GDP	PD/GDP	PD.	GDP	PD/GDP	PD.	GDP	PD/GDP
	billon USD		%	billon USD		%	billon USD		%	billon USD		%
2009	69.33	207.56	33.40	32.51	89.30	36.40	189.97	439.74	43.20	93.75	130.76	71.70
2010	77.56	209.07	37.10	37.04	90.35	41.00	228.88	479.83	47.70	96.17	131.92	72.90
2011	90.68	229.56	39.50	43.11	99.11	43.50	257.28	528.30	48.70	103.20	141.76	72.80
2012	92.32	208.86	44.20	48.94	94.47	51.80	240.29	498.52	78.20	91.09	128.48	70.90
2013	93.99	211.69	44.40	54.02	98.75	54.70	266.76	521.02	51.20	96.28	135.41	71.10
2014	87.72	209.36	41.90	54.21	101.33	53.50	243.57	542.48	44.90	99.38	140.77	70.60
2015	74.65	188.03	39.70	45.93	88.50	51.90	222.19	477.81	46.50	88.67	125.07	70.90
2016	71.83	196.27	36.60	46.63	89.68	52.00	227.34	472.63	48.10	88.00	128.47	68.50
2017	74.77	218.63	34.20	48.97	95.45	51.30	235.88	526.51	44.80	94.21	142.96	65.90
2018	79.90	248.91	32.10	52.41	105.87	49.50	249.06	587.41	42.40	101.39	160.42	63.20
2019	75.71	250.68	30.20	50.61	105.43	48.00	235.36	595.86	39.50	96.94	163.47	59.30
2020	94.61	241.98	39.10	62.97	101.89	61.80	310.78	580.89	53.50	105.56	149.94	70.40

The rapid increase of ratio value in 2020 in all studied countries was caused by the COVID-19 pandemic, due to the consequences of which there was a shortfall in GDP and a significant increase of public debt, which contributed to exceeding the maximum level of debt security in Slovakia (61.80%) and Hungary (70.40%) and substantially worsened the debt situation in Czech Republic and Poland, despite of the fact that now this ratio in the last two countries is within the normal range.

Ratios of the value of deficit load on the economy of the Visegrad Group countries. During 2009-2019 all the Visegrad Group countries tended to decrease the indicator investigated, that demonstrated an increase in the development level of these countries. In 2009-2012-Czech Republic (5.40% -3.90%), in 2009-2012 and 2014 Slovakia (8.10% - 4.40% and correspondingly 3.10%), in 2009-2014 Poland (7.20% -3.70%), in 2009-2011 Hungary (4.60% -5.30%) had exceeded the limits of security caused by the economic crisis, high inflation rates, the use of most of their resources for current consumption, and the implementation of significant payments by debt obligations.

Access to a safe level in 2015-2019 has been achieved through the implementing active functions of a deficit in the economy - financing national investment programs, gaining more GDP growth and more. As a consequence, it demonstrates the stabilization of the situation and the improvement of sustainability and security of public budget in the Visegrad countries (Table 3).

Table 3. Dynamics of coefficients of the level of deficit leverage for the economy of the Visegrad Group countries.
Source: own processing based on data from Visegrad Group.

Years	Czech Republic			Slovakia			Poland			Hungary		
	Def. (Prof.)	GDP	Def.(Prof.)/ GDP	Def. (Prof.)	GDP	Def.(Prof.)/ GDP	Def. (Prof.)	GDP	Def.(Prof.)/ GDP	Def. (Prof.)	GDP	Def.(Prof.)/ GDP
	billon USD		%	billon USD		%	billon USD		%	billon USD		%
2009	11.21	207.56	5.40	7.23	89.30	8.10	31.66	439.74	7.20	6.01	130.76	4.60
2010	8.78	09.07	4.20	6.78	90.35	7.50	35.51	479.83	7.40	5.94	131.92	4.50
2011	6.20	29.56	2.70	4.36	99.11	4.40	25.89	528.30	4.90	7.51	141.76	5.30
2012	8.15	08.86	3.90	4.16	94.47	4.40	18.94	498.52	3.80	3.08	128.48	2.40
2013	2.54	11.69	1.20	2.86	98.75	2.90	21.88	521.02	4.20	3.52	135.41	2.60
2014	4.40	09.36	2.10	3.14	101.33	3.10	20.07	542.48	3.70	3.94	140.77	2.80
2015	1.13	88.03	0.60	2.39	88.50	2.70	12.42	477.81	2.60	2.50	125.07	2.00
2016	1.37	96.27	0.70	2.24	89.68	2.50	11.34	472.63	2.40	2.31	128.47	1.80
2017	3.28	18.63	1.50	0.95	95.45	1.00	7.37	526.51	1.40	3.57	142.96	2.50
2018	2.24	48.91	0.90	1.16	105.87	1.10	1.17	587.41	0.20	3.53	160.42	2.20
2019	0.50	50.68	0.20	1.37	105.43	1.30	4.17	595.86	0.70	3.43	163.47	2.10
2020	7.66	41.98	7.30	9.07	101.89	8.90	61.00	580.89	10.50	12.45	149.94	8.30

However, it should be noted that in 2020 the ratio of this coefficient was the worst in all studying period. So, in all the countries of the Visegrad group, there is a negative trend towards an increase of this coefficient and a significant excess of the limit. This is due to the growth in the budget deficit through an increase in health care expenses caused by the need for additional financing the medical industry in the fight against COVID-19, as well as a fall of GDP.

Ratios of the value of debt load on the population of the Visegrad Group countries. During the investigated period there is a significant excess of the maximum permissible level of debt burden on the population in all the countries of the Visegrad Four: in Czech Republic and Poland, on average-by 23.6 times, in Slovakia-by 29.9 times, in Hungary-by 34.9 times Also, the negative thing is the tendency of increasing this indicator in each country. It means that the debt burden on the population of the countries is excessive, and it affects the general economic and social condition of the people, exacerbates the economic relations between the state and the citizens, creates a threat to sustainability and security of public budget.

In this regard, the governments of the Visegrad Group countries urgently need to take a number of measures to reverse the negative trend, namely, to develop a clear strategy of sustainable (balanced) economic development and to define a wide range of measures to manage national debt, minimizing payments for its servicing, budget deficit, balance of payments, improve borrowed funds efficiency, create new jobs. It will improve the investment climate and raise the living standard of the population while avoiding debt sustainability and security problems (Table 4).

Table 4. Dynamics of coefficients of the level of debt leverage for the population of the Visegrad Group countries.
Source: own processing based on data from Visegrad Group

Years	Czech Republic			Slovakia			Poland			Hungary		
	PD.	P.	PD./P.	PD.	P.	PD./P.	PD.	P.	PD./P.	PD.	P.	PD./P.
	Billon USD	mln. people	USD per person	billon USD	mln. people	USD per person	billon USD	mln. people	USD per person	lon USD	mln. people	USD per person
2009	69.33	10.444	6637.79	32.51	5.386	6035.13	189.97	38.152	4979.23	93.75	10.023	9353.98
2010	77.56	10.474	7405.48	37.04	5.391	6871.36	228.88	38.043	6016.32	96.17	10.000	9616.97
2011	90.68	10.496	8639.12	43.11	5.398	7986.82	257.28	38.063	6759.38	103.20	9.972	10349.11
2012	92.32	10.511	8782.81	48.94	5.408	9048.72	389.84	38.063	10242.04	91.09	9.920	9182.69
2013	93.99	10.514	8939.54	54.02	5.413	9978.99	266.76	38.040	7012.68	96.28	9.893	9731.78
2014	87.72	10.525	8334.62	54.21	5.419	10003.98	243.57	38.012	6407.81	99.38	9.866	10073.34
2015	74.65	10.546	7078.32	45.93	5.424	8468.20	222.18	37.986	5849.04	88.67	9.843	9008.90
2016	71.83	10.566	6798.68	46.63	5.431	8586.56	227.34	37.970	5987.23	88.00	9.814	8966.98
2017	74.77	10.594	7057.91	48.97	5.439	9002.73	235.88	37.975	6211.36	94.21	9.788	9625.12
2018	79.90	10.630	7516.47	52.41	5.447	9621.01	249.06	37.975	6558.57	101.39	9.776	10370.85
2019	75.71	10.670	7095.16	50.61	5.454	9278.77	235.36	37.971	6198.54	96.94	9.770	9921.98
2020	94.61	10.668	8868.97	62.97	5.455	11543.18	310.78	37.919	8195.79	105.56	9.741	10836.44

It is necessary to note that in 2020 the debt burden on the population increased by almost 2,000 USD per year (in Slovakia, the increase occurred by 2,264.41 USD). And this exceeds the maximum permissible rate at about 37 times.

One of the main factors for the worsening of this situation was the financing of the consequences of the COVID-19 pandemic, which influenced both the growth of public debt and increasing the debt burden on citizens.
Ratios of budgetary independence of the Visegrad Group countries. During the researched period, the permissible values of budgetary independence indicators are observed in all the Visegrad Group countries, indicating that they are in compliance with sustainability and security of public budget (except Poland in 2020). Despite the budget deficits that exist in all countries from 2009 to 2020 (except Czech Republic in 2016-2019), the Visegrad countries find an opportunity to cover the difference between expenditures and revenues at the expense of additional sources (mainly their own). It does not prevent the economy from maintaining a stable high level. It should also be noted that there is an overall positive upward trend in fiscal independence (except 2020, when the epidemiological situation affected in a significant decrease in the value of this indicator) (Table 5).

Table 5. Dynamics of coefficients of the budgetary independence of the Visegrad Group countries.
Source: own processing based on data from Visegrad Group

Years	**Czech Republic**			**Slovakia**			**Poland**			**Hungary**		
	Income	Expenses	In./Exp.	Income	Expenses	In./Exp.	Income	Expenses	In./Exp.	Income	Expenses	In./Exp.
	billon USD		%	billon USD		%	billon USD		%	billon USD		%
2009	79.91	91.12	87.70	32.42	39.65	81.76	165.34	197.00	83.93	59.76	65.77	90.85
2010	81.54	90.32	90.28	31.35	38.13	82.23	184.25	219.76	83.84	58.97	64.90	90.85
2011	91.82	98.02	93.68	36.67	41.03	89.37	206.04	231.92	88.84	62.52	70.03	89.27
2012	84.17	92.32	91.18	34.58	38.73	89.27	194.92	213.87	91.14	60.39	63.47	95.14
2013	86.58	89.12	97.15	38.91	41.77	93.14	200.07	221.95	90.14	64.46	67.98	94.82
2014	83.74	88.14	95.01	40.73	43.88	92.84	209.94	230.01	91.27	66.72	70.67	94.42
2015	76.72	77.84	98.55	38.14	40.53	94.10	186.82	199.25	93.76	60.78	63.29	96.05
2016	79.49	78.12	101.76	36.05	38.29	94.15	182.91	194.25	94.16	58.33	60.64	96.19
2017	88.55	85.27	103.85	38.66	39.61	97.59	209.55	216.92	96.60	63.62	67.19	94.68
2018	103.30	101.06	102.22	43.19	44.36	97.37	242.60	243.78	99.52	71.39	74.92	95.29
2019	103.78	103.28	100.49	43.75	45.12	96.96	246.09	250.26	98.33	71.93	75.36	95.44
2020	98.24	115.91	84.76	43.10	52.17	82.62	236.42	297.42	79.49	65.67	78.12	84.07

Ratios of budgetary performance of the Visegrad Group countries. During the investigated period (except 2020), there has been a positive trend towards an increase in the budget performance indicator in all the Visegrad Group countries: the most rapid shift is observed in Slovakia (by $ 930.58 per person). It partially compensates for the failure to meet the maximum level of debt load on the population. The results also show that the budgets of the countries researched ensure the proper implementation of their functions, effectively implement state programs and investment projects that promote state development (Table 6).

Table 6. Dynamics of coefficients of the budgetary performance of the Visegrad Group countries.
Source: own processing based on data from Visegrad Group.

Years	**Czech Republic**			**Slovakia**			**Poland**			**Hungary**		
	Income	P.	Income/P.	Income	P.	Income/P.	Income	P.	Income/P.	Income	P.	Income/P.
	Billon USD	mln. people	USD per person	billon USD	mln. people	USD per person	billon USD	mln. people	USD per person	billon USD	mln. people	USD per person
2009	79.91	0.444	7651.34	32.42	5.386	6018.55	165.34	38.152	4333.78	59.76	10.023	5962.02
2010	81.54	0.474	7784.73	31.35	5.391	5815.52	184.25	38.043	4843.33	58.97	10.000	5896.82
2011	91.82	0.496	8748.48	36.67	5.398	6793.39	206.04	38.063	5413.05	62.52	9.972	6269.17
2012	84.17	0.511	8007.86	34.58	5.408	6393.49	194.92	38.063	5121.02	60.39	9.920	6087.26
2013	86.58	0.514	8234.85	38.91	5.413	7187.79	200.07	38.040	5259.51	64.46	9.893	6515.23
2014	83.74	0.525	7956.67	40.73	5.419	7517.01	209.94	38.012	5522.99	66.72	9.866	6763.12
2015	76.72	0.546	7274.44	38.14	5.424	7032.36	186.82	37.986	4918.23	60.78	9.843	6175.36
2016	79.49	0.566	7523.13	36.05	5.431	6638.07	182.91	37.970	4817.17	58.33	9.814	5943.08
2017	88.55	0.594	8358.05	38.66	5.439	7107.42	209.55	37.975	5518.13	63.62	9.788	6499.51
2018	103.30	0.630	9717.56	43.19	5.447	7930.05	242.60	37.975	6388.42	71.39	9.776	7302.26
2019	103.78	0.670	9726.48	43.75	5.454	8022.27	246.09	37.971	6481.00	71.93	9.770	7362.01
2020	98.24	0.668	9209.21	43.10	5.455	7900.91	236.42	37.919	6234.93	65.67	9.741	6741.99

The negative trend towards a decline in the values of the budget performance ratios in all countries of the Visegrad Group in 2020 was provoked by a significant decrease in budget revenues due to the introduction of a number of tax incentives for businesses that suffer losses due to numerous restrictions and sanctions from the COVID-19 pandemic,

which affected the volume tax revenues and, as a result, led to significant budget losses.
The ratios of security of public budget of the population of the Visegrad Group countries. During the investigated period, there has a positive upward trend of the level of security of public budget in Poland (by $ 507.94 per person) and Hungary (by $ 143.05 per person). It indicates that the budgets of these countries are socially oriented, spending on the population is increasing at a faster rate than its size, the financial capacity of the executive authorities is observed, and the level of sustainability and security of public budget is sufficient to finance constitutionally guaranteed measures for the life support of citizens. At the same time, we see a decrease in this indicator in Czech Republic (by $ 782.47 per person) and Slovakia (by $ 218.23 per person), which is due to less spending capacity to finance social direction. The governments of these countries in the coming periods should look for additional sources of resource formation to provide wealth to the population (Table 7). COVID-19 pandemic did not affect the positive trend towards an increase in the value of this indicator in 2020. This means that the governments of the Visegrad Four countries continue to increase fiMacinga for the social sphere, including additional medical costs.

Table 7. Dynamics of coefficients of the security of public budget of the Visegrad Group countries.
Source: own processing based on data from Visegrad Group.

Years	**Czech Republic**			**Slovakia**			**Poland**			**Hungary**		
	Expenses	P.	Expenses /P.	Expenses	P.	Expenses/ P.	Expenses	P.	Expenses/ P.	Expenses	P.	Expense/ P.
	billon USD	mln. people	USD Per person	billon USD	mln. people	USD per person	billon USD	mln. people	USD per person	billon USD	mln. people	USD per person
2009	91.12	10.444	8724.52	39.65	5.386	7361.53	197.00	38.152	5163.65	65.77	10.023	6562.14
2010	90.32	10.474	8623.09	38.13	5.391	7072.47	219.76	38.043	5776.68	64.90	10.000	6490.46
2011	98.02	10.496	9339.00	41.03	5.398	7601.25	231.92	38.063	6093.15	70.03	9.972	7022.61
2012	92.32	10.511	8782.81	38.73	5.408	7162.11	213.87	38.063	5618.71	63.47	9.920	6398.10
2013	89.12	10.514	8476.46	41.77	5.413	7716.84	221.95	38.040	5834.77	67.98	9.893	6871.10
2014	88.14	10.525	8374.40	43.88	5.419	8096.68	230.01	38.012	6051.02	70.67	9.866	7162.63
2015	77.84	10.546	7381.42	40.53	5.424	7472.90	199.25	37.986	5245.27	63.29	9.843	6429.48
2016	78.12	10.566	7393.10	38.29	5.431	7050.89	194.25	37.970	5115.91	60.64	9.814	6178.71
2017	85.27	10.594	8048.49	39.61	5.439	7282.91	216.92	37.975	5712.23	67.19	9.788	6864.65
2018	101.06	10.630	9506.82	44.36	5.447	8143.85	243.78	37.975	6419.36	74.92	9.776	7663.27
2019	103.28	10.670	9679.49	45.12	5.454	8273.57	250.26	37.971	6590.85	75.36	9.770	7713.37
2020	115.91	10.668	10865.06	52.17	5.455	9563.28	297.42	37.919	7843.45	78.12	9.741	8019.58

Financial productivity ratios of the budgets of the Visegrad Group countries. It should be noted that the budget productivity ratio increases in Czech Republic (from 28.42 in 2013 to 340.38 in 2016), Slovakia (from 49.42 in 2010 to 96.18 in 2011, and from 21.61 in 2012 to 869.35 in 2015), Poland (from 24.61 in 2010 to 36.06 in 2011, and from 20.01 in 2012 to 812.24 in 2015 and from 102.00 in 2016 to 154.11 in 2017), Hungary (from 19.66 in 2011 to 22.11 in 2012, and from 17.82 in 2013 to 921.62 in 2016). This indicates that these years there has been a positive tendency to increase, which is due to the efficiency of use of budgetary funds, whereby a high level of budgetary potential, targeted use of investments is achieved, social protection of the population is achieved, that in turn influences the development of the economy, that is, promotes to ensure the sustainable development of the Visegrad Group countries. The opposite (negative) situation is observed in other periods, which indicates a threat to the fiscal sustainability and security of the investigated countries in the years of diminishing financial performance ratios (Table 8).

Economic efficiency ratios of the budgets of the Visegrad Group countries. It should be noted that the economic efficiency ratio of the budget increases in Czech Republic (from 69.49 in 2013 to 840.44 in 2016 and from 116.77 in 2018 to 118.12 in 2019), Slovakia (from 142.42 in 2010 to 259.94 in 2011, and also from 59.04 in 2012 to 2017.05 in 2015), Poland (from 64.10 in 2010 to 92.46 in 2011, from 51.18 in 2012 to 2077.33 in 2015, from 263.56 in 2016 to 387.21 in 2017, from 128.95 in 2018 to 135.79 in 2019), Hungary (from 44.57 in 2011 to 47.04 in 2012, and from 37.43 in 2013 to 2030.01 in 2016). It indicates that these years there has been a positive trend to increase, which is due to the efficiency and effectiveness of using budget funds, which allows to achieve the necessary results of socio-economic development of the Visegrad Group countries with minimal spending budget resources. The opposite (negative) situation is observed in other periods, which indicates a threat to the sustainability and security of public budget of the countries investigated in the years of diminishing economic efficiency ratios (Table 9).

Table 8. Dynamics of coefficients of the financial productivity of the Visegrad Group countries. *Source: own processing based on data from Visegrad Group.*

Years	Czech Republic				Slovakia				Poland				Hungary			
	In.	Exp.	I.	$C_{\cdot fin.pr.}$	In.	Exp.	I.	$C_{\cdot fin.pr.}$	In.	Exp.	I.	$C_{\cdot fin.pr.}$	In.	Exp.	I.	$C_{\cdot fin.pr.}$
	billon USD		coefficients		billon USD		coefficients		billon USD		coefficients		billon USD		coefficients	
2009	79.91	91.12	0.010	-	32.42	39.65	0.016	-	165.34	197.00	0.038	-	59.76	65.77	0.042	-
2010	81.54	90.32	0.015	89.48	31.35	38.13	0.010	49.42	184.25	219.76	0.026	24.61	58.97	64.90	0.049	21.35
2011	91.82	98.02	0.019	67.78	36.67	41.03	0.039	96.18	206.04	231.92	0.042	36.06	62.52	70.03	0 039	19.66
2012	84.17	92.32	0.033	45.19	34.58	38.73	0.036	21.61	194.92	213.87	0.036	20.01	60.39	63.47	0.057	22.11
2013	86.58	89.12	0.014	28.42	38.91	41.77	0.014	27.90	200.07	221.95	0.010	25.99	64.46	67.98	0.017	17.82
2014	83.74	88.14	0.003	67.12	40.73	43.88	-0.001	69.66	209.94	230.01	0.001	94.59	66.72	70.67	-0.002	57.74
2015	76.72	77.84	0.003	290.13	38.14	40.53	-0.003	869.35	186.82	199.25	-0.009	812.24	60.78	63.29	-0.001	430.08
2016	79.49	78.12	0.007	340.38	36.05	38.29	-0.005	296.48	182.91	194.25	-0.007	102.00	58.33	60.64	0.004	921.62
2017	88.55	85.27	0.025	161.93	38.66	39.61	0.013	201.90	209.55	216.92	0.021	154.11	63.62	67.19	0.023	262.28
2018	103.30	101.06	0.021	48.46	43.19	44.36	0.025	83.88	242.60	243.78	0.018	53.26	71.39	74.92	0.029	46.19
2019	103.78	103.28	0.028	48.90	43.75	45.12	0.027	39.45	246.09	250.26	0.022	56.08	71.93	75.36	0.033	33.11

Table 9. Dynamics of coefficients of the economic efficiency of budgets the Visegrad Group countries. *Source: own processing based on data from Visegrad Group*

Years	Czech Republic				Slovakia				Poland				Hungary			
	GDP	Exp.	I.	$C_{\cdot ec.ef}$	GDP	Exp.	I.	$C_{\cdot ec.ef.}$	GDP	Exp.	I.	$C_{\cdot ec.ef}$	GDP	Exp.	I.	$C_{\cdot ec.ef.}$
	billon USD		coefficients		billon USD		coefficients		billon USD		coefficients		billon USD		coefficients	
2009	6	91.12	0.010	-	89.3	39.65	0.016	-	439.74	197.00	0.038	-	130.76	65.77	0.042	-
2010	209.07	90.32	0.015	229.45	90.35	38.13	0.010	142.42	479.83	219.76	0.026	64.10	131.92	64.90	0.049	47.75
2011	229.56	98.02	0.019	169.45	99.11	41.03	0.039	259.94	528.3	231.92	0.042	92.46	141.76	70.03	0.039	44.57
2012	208.86	92.32	0.033	112.14	94.47	38.73	0.036	59.04	498.52	213.87	0.036	51.18	128.48	63.47	0.057	47.04
2013	211.69	89.12	0.014	69.49	98.75	41.77	0.014	70.82	521.02	221.95	0.010	67.67	135.41	67.98	0.017	37.43
2014	209.36	88.14	0.003	167.80	101.33	43.88	-0.001	173.27	542.48	230.01	0.001	244.41	140.77	70.67	-0.002	121.82
2015	188.03	77.84	0.003	711.10	88.5	40.53	-0.003	2017.05	477.81	199.25	-0.009	2077.33	125.07	63.29	-0.001	884.93
2016	196.27	78.12	0.007	840.44	89.68	38.29	-0.005	737.51	472.63	194.25	-0.007	263.56	128.47	60.64	0.004	2030.01
2017	218.63	85.27	0.025	399.83	95.45	39.61	0.013	498.52	526.51	216.92	0.021	387.21	142.96	67.19	0.023	589.40
2018	248.91	101.06	0.021	116.77	105.87	44.36	0.025	205.59	587.41	243.78	0.018	128.95	160.42	74.92	0.029	103.81
2019	250.68	103.28	0.028	118.12	105.43	45.12	0.027	95.07	595.86	250.26	0.022	135.79	163.47	75.36	0.033	75.24

The ratios of financial support efficiency for health care in the Visegrad Group countries. During the investigated period, all countries of the Visegrad Group observed compliance with the limits of the efficiency ratios of health care financial support. It demonstrates the proper level of funding for the medical industry, which is reflected in the adequate provision of emergency and emergency care to the population of the considered countries, and the healthcare institutions with the necessary modern equipment and facilities (Table 10).

The COVID-19 pandemic, which caused the need to increase healthcare financing in 2020-2021, would certainly affect the corresponding performance indicators, the value of which would increase significantly. The authors believe that the limit of the permissible level of this coefficient for the next years should be set at least at 8% (instead of the currently approved 4%), because the fight against the consequences of the epidemic requires an increase in expenditures in the medical industry at least twice.

The ratios of education financial support efficiency of the Visegrad Group countries. During the investigated period in all countries of the Visegrad Group there was a failure to observe the limits of the ratios of education financial support efficiency. It demonstrates a lack of funding for public and individual training needs, which threatens sustainability and security of public budget. In this regard, the Government should take steps to create conditions for the development of the education sector through additional sources of financing: attracting investors, self-financing, etc. (Table 11).

Table 10. Dynamics of coefficients of efficiency of financial security of healthcare of the Visegrad Group countries, % *Source: own processing based on data from Visegrad Group*

Years	**Czech Republic**	**Slovakia**	**Poland**	**Hungary**
	Expenses for healthcare/GDP	Expenses for healthcare/GDP	Expenses for healthcare /GDP	Expenses for healthcare /GDP
2009	7.3	7.9	6.6	7.2
2010	6.9	7.7	6.4	7.5
2011	7.0	7.4	6.2	7.5
2012	7.0	7.6	6.2	7.4
2013	7.8	7.5	6.4	7.2
2014	7.7	6.9	6.4	7.1
2015	7.2	6.8	6.4	6.9
2016	7.1	7.1	6.5	7.0
2017	7.2	6.8	6.6	6.8
2018	7.6	6.7	6.3	6.7
2019	7.6	6.7	6.3	6.7

Recommended limit – over 4%

Table 11. Dynamics of coefficients of efficiency of financial support of education of the Visegrad Group countries, %. *Source: own processing based on data from Visegrad Group.*

Years	**Czech Republic**	**Slovakia**	**Poland**	**Hungary**
	Expenses for education/GDP	Expenses for education/GDP	Expenses for education/GDP	Expenses for education /GDP
2009	4.2	4.0	5.0	5.0
2010	4.1	4.1	5.1	4.8
2011	4.3	3.9	4.8	4.6
2012	4.3	3.9	4.8	4.2
2013	4.1	4.1	4.9	4.2
2014	4.0	4.2	4.9	4.6
2015	5.8	4.6	4.8	4.5
2016	5.6	3.9	4.6	4.7
2017	3.9	3.9	4.6	4.7
2018	3.8	3.7	4.5	4.8
2019	3.7	3.7	4.5	4.8

Recommended limit – over 8.3%

The ratios of income elasticity from GDP show how the income of the Visegrad countries (increases/decreases) as GDP changes by 1%.

- Czech Republic: the largest shift in income due to a change in GDP by 1% is observed in 2014/2013 (with a decrease in GDP by 1%, income decreased by 2.98%); the smallest shift - in 2019/2018 (with an increase in GDP by 1% income increased by 0.66%);
- Slovakia: the largest shift in income due to a change in GDP by 1% is observed in 2016/2015 (with a 1% increase in GDP income decreased by 4.11%) - the situation is negative, as it indicates inefficient mobilization of resources; the smallest shift - in 2020/2019 (with a 1% decrease in GDP, income decreased by 0.45%);
- Poland: the largest shift in income due to a change in GDP by 1% is observed in 2016/2015 (with a 1% decrease in GDP income decreased by 1.93%); the smallest shift - in 2013/2012 (with a 1% increase in GDP income increased by 0.59%);
- Hungary: the largest shift in income due to a change in GDP by 1% is observed in 2010/2009 and in 2016/2015 (with a 1% increase in GDP income decreased by 1.49% in both of the above periods) - the situation is negative, as it indicates inefficient mobilization of resources; the smallest shift - in 2012/2011 (with a 1% decrease in GDP, income decreased by 0.36%).

It should be noted that the shift is positive when GDP increases by 1% the Visegrad Group countries' income grows at a faster rate (more than 1%) (Table 12).

GDP elasticity ratios show how expenditures of the Visegrad countries (increases/decreases), when GDP changes by 1%:

- Czech Republic: the largest shift in expenditures due to a change in GDP by 1% was observed in 2020/2019 (with a 1% decrease in GDP, expenditures increased by 3.52%); the smallest shift - in 2016/2015 (when GDP increased by 1%, expenditures increased by 0.08%);

- Slovakia: the largest shift in expenditures due to a change in GDP by 1% is observed in 2020/2019 (with a 1% decrease in GDP, expenditure increased by 4.65%); the smallest shift in 2017/2016 (when GDP increased by 1%, expenditures increased by 0.54%);
- Poland: the largest shift in expenditures due to a change in GDP by 1% is observed in 2020/2019 (with a decrease in GDP by 1%, expenditure increased by 7.50%); the smallest shift - in 2011/2010 (when GDP increased by 1%, expenditures increased by 0.55%);
- Hungary: the largest shift in expenditures due to a change in GDP by 1% is observed in 2016/2015 (with a 1% increase in GDP, expenditures decreased by 1.54%); the smallest shift - in 2019/2018 (with GDP increasing by 1%, expenditures increased by 0.31%).

Table 12. Dynamics of income elasticity coefficients from changes in GDP of the Visegrad Group countries, %.
Source: own processing based on data from Visegrad Group

Years	**Czech Republic**			**Slovakia**			**Poland**			**Hungary**		
	$R_{inc.\ Income}$	$R_{inc.\ GDP}$	$C_{el.\ Income}$	$R_{inc.\ Income}$	$R_{inc.\ GDP}$	$C_{el.\ Income}$	$R_{inc\ Income}$	$R_{inc.\ GDP}$	$C_{el.\ Income}$	$R_{inc.\ Income}$	$R_{inc.\ GDP}$	$C_{el.\ Income}$
2010/2009	04	0.73	2.80	-3.28	1.18	-2.79	11.44	9.12	1.25	-1.32	0.89	-1.49
2011/2010	12. 62	9.80	1.29	16.97	9.70	1.75	11.82	10.10	1.17	6.02	7.46	0.81
2012/2011	-8.33	-9.02	0.92	-5.71	-4.68	1.22	-5.39	-5.64	0.96	-3.41	-9.37	0.36
2013/2012	2.86	1.35	2.11	12.53	4.53	2.77	2.64	4.51	0.59	6.74	5.39	1.25
2014/2013	-3.28	-1.10	2.98	4.70	2.61	1.80	4.93	4.12	1.20	3.52	3.96	0.89
2015/2014	-8.39	-10.19	0.82	-6.36	-12.66	0.50	-11.01	11.92	0.92	-8.90	-11.15	0.80
2016/2015	3.61	4.38	0.82	-5.48	1.33	-4.11	-2.10	-1.08	1.93	-4.04	2.72	-1.49
2017/2016	11.39	11.39	1.00	7.23	6.43	1.12	14.57	11.40	1.28	9.07	11.28	0.80
2018/2017	16.66	13.85	1.20	11.74	10.92	1.08	15.77	11.57	1.36	12.21	12.21	1.00
2019/2018	0.47	0.71	0.66	1.29	-0.42	-3.11	1.44	1.44	1.00	0.76	1.90	0.40
2020/2019	-5.34	-3.47	1.54	-1.49	-3.36	0.45	3.93	-2.51	1.56	-8.69	-8.28	1.05

According to this indicator of sustainability and security of public budget, the situation is positive, as the results indicate the targeted use of budgetary funds (Table 13).

Table 13. Dynamics of coefficients of elasticity of expenditures from changes in GDP of the Visegrad Group countries, %.
Source: own processing based on data from Visegrad Group.

Years	**Czech Republic**			**Slovakia**			**Poland**			**Hungary**		
	$R_{inc.\ Expenses}$	$R_{inc.\ GDP}$	$C_{el.\ Expenses}$	$R_{inc.\ Expenses}$	$R_{inc.\ GDP}$	$C_{el\ Expenses}$	$R_{inc.\ Expenses}$	$R_{inc.\ GDP}$	$C_{el.\ Expenses}$	$R_{inc.\ Expenses}$	$R_{inc.\ GDP}$	$C_{el.\ Expenses}$
2010/2009	-0.88	0.73	-1.21	-3.84	1.18	-3.26	11.55	9.12	1.27	-1.32	0.89	-1.49
2011/2010	8.53	9.80	0.87	7.62	9.70	0.79	5.53	10.10	0.55	7.90	7.46	1.06
2012/2011	-5.82	-9.02	0.65	-5.60	-4.68	1.20	-7.79	-5.64	1.38	-9.37	-9.37	1.00
2013/2012	-3.46	1.35	-2.55	7.84	4.53	1.73	3.78	4.51	0.84	7.10	5.39	1.32
2014/2013	1.10	-1.10	1.00	5.04	2.61	1.93	3.63	4.12	0.88	3.96	3.96	1.00
2015/2014	-11.68	10.19	1.15	-7.62	-12.66	0.60	-13.38	-11.92	1.12	-10.44	-11.15	0.94
2016/2015	0.35	4.38	0.08	-5.53	1.33	-4.14	-2.51	-1.08	2.31	-4.18	2.72	-1.54
2017/2016	9.15	11.39	0.80	3.44	6.43	0.54	11.67	11.40	1.02	10.81	11.28	0.96
2018/2017	18.52	13.85	1.34	11.99	10.92	1.10	12.38	11.57	1.07	11.50	12.21	0.94
2019/2018	2.20	0.71	3.09	1.72	-0.42	-4.15	2.66	1.44	1.85	0.59	1.90	0.31
2020/2019	12.23	-3.47	-3.52	15.61	-3.36	-4.65	18.84	-2.51	-7.50	3.66	-8.28	-0.44

The results of correlation analysis of the studied factors.

Based on the correlation analysis among the complex of investigated factors that can influence the productive feature

- the level of deficit load on the economy, those factors that are characterized by a sufficiently high level of correlation with the specified indicator were selected, that is, for the research the largest factors of influence were selected (those that had little effect on the resultant ratio were not investigated).

Consequently, it was determined that:

- in Czech Republic, the greatest impact on the level of deficit leverage for the economy is made by the indicators of the level of debt leverage for the population, budgetary independence, and the effectiveness of financial support for healthcare - $R^2 = 82.63\%$, respectively, other factors affect by 17.37%;

- in Slovakia, the greatest influence on the level of deficit leverage for the economy is made by the indicators of budgetary independence, budgetary efficiency and effectiveness of financing health care - R^2 = 99.87%, respectively, other factors affect by 0.13%;
- in Poland, the greatest influence on the level of deficit leverage for the economy is made by the indicators of budgetary independence, budgetary performance and efficiency of financial support of education - R^2= 99.80%, accordingly other factors affect by 0.20%;
- in Hungary, the greatest influence the level of deficit leverage for the economy is made by the indices of the level of debt security budgetary independence and the effectiveness of financial support for healthcare - R^2= 99.90%, accordingly other factors affect by 0.10%.

To determine the quantitative measurement of the impact of each factor on the productive feature - the level of deficit load on the economies of the Visegrad Group countries, a regression analysis was conducted (table 14), which created basis for constructing regression models (formulas 1-8).

Table 14. Regression analysis matrix to determine the impact of factors on the level of deficit load on the economy of the Visegrad Group countries. *Source: own processing based on data from Visegrad Group.*

Indicator	**Countries**			
	Czech Republic	Slovakia	Poland	Hungary
Multiple R (r-correlation ratio), %	90.90	99.94	99.90	99.95
R-squared (determination ratio), %	82.63	99.87	99.80	99.90
Observations (number of investigated periods), p.	10	10	10	10
	Regression ratio			
Y-section (free member, no economic value)	28.49	45.30	48.00	47.50
Debt Security Ratio (DS)	N/A**			0.02
Ratios of the value of debt load on the population DLP)	0.01	N/A**		
Budget Independence Ratio (BI)	-0.18	-0.43	-0.48	- 0.49
Budgetary Performance Ratio (BP)	N/A**	-0.01	0.01	N/A**
Healthcare Financial Support Efficiency Ratio (HFS)	-1.59	-0.27	N/A**	-0.02
Ratio of Education Financial Support Efficiency (FSE)	N/A**		-0.28	N/A**

** N/A - not investigated because of the low level of impact on the productive feature, which was determined on the basis of correlation analysis due to multicollinearity (significant and negligible influence of budgetary stability and security ratios on the level of deficit load on the economy was revealed):

(1) in Czech Republic:

$$Y = 0.01X_1 - 0.18X_2 - 1.59X_3 + 28.49$$
$$=>$$
$$P = 0.01DLP - 0.18BI - 1.59HFS + 28.49$$

(2) in Slovakia:

$$Y = -0.43X_1 - 0.01X_2 - 0.27X_3 + 45.30$$
$$=>$$
$$P = -0.43BI - 0.01BP - 0.27HFS + 45.30$$

(3) in Poland:

$$Y = -0.48X_1 + 0.01X_2 - 0.28X_3 + 48.00$$
$$=>$$
$$P = -0.48BI + 0.01BP - 0.28FSE + 48.00$$

(4) in Hungary:

$$Y = 0.02X_1 - 0.49X_2 - 0.02X_3 + 47.50$$
$$=>$$
$$P = 0.02DS - 0.49BI - 0.02HFS + 47.50$$

Consequently, the budgetary independence ratio had the greatest impact on changing the level of deficit load in the economy in all the Visegrad Group countries (except Czech Republic). At the same time, it influenced inversely,

that is, its increase has led to a decrease in the ratio and an increase in the level of deficit load on the economy, which is positive (the limit - no more than 3%). It means that a greater development of the state is achieved when revenues exceed 80% of expenses.

The level of deficit load on the Czech economy is greatly influenced by the effectiveness of financial support for healthcare, which indicates the importance of professional training in medical industry (inverse proportionality), to a lesser extent, the budgetary performance and level of debt leverage for the population. Considering the situation in Slovakia, it should be noted that, in addition to budgetary independence, the ratio of budgetary performance and efficiency ratio of financial support for health care are also affected by the result, and the inverse relationship indicates that the increase of these ratios decreases the resultant index and increases the level of deficit load on the economy. As for Poland, in this country the level of deficit burden on the economy is influenced by the coefficients of efficiency of financial support of education and budget independence (inverse proportionality), as well as budget performance (direct proportionality), in Hungary - the ratios of the level of debt security (direct proportionality), the ratios of budget independence and healthcare financial support efficiency ratio (inverse proportionality).

Impact

It should be noted that in 2020 most of the indicators of fiscal sustainability and security in the Visegrad countries did not reach the required norm or had a negative tendency to decrease. This is a consequence of the fight against the global COVID-19 pandemic. The authors of the article are sure that sufficient financing the healthcare industry, which will make it possible to vaccinate the population and ensure collective immunity, improve the situation and in coming years it will be a positive change in the economies of the studied countries, which can be seen on the results of the corresponding coefficients proposed in this scientific work.

An urgent problem of effective management of the national and regional economies of the investigated countries is the development of a scientifically sound methodology for ensuring sustainability and security of public budget through the identification of mechanisms of imbalance of budgetary processes. Solution to the problem will ensure the efficiency and balance of budgets of all levels, preserving the welfare of the population and a possible breakthrough in the socio-economic development of the Visegrad countries.

Particularly important in the process of ensuring the implementation of the strategy of achieving stability and security of public budget of the Visegrad Group countries is the legal control, which means legislative consolidation and consistent implementation of a legal instrument that enshrines the principles of a system of precautionary measures in the direction of strengthening the budget efficiency, and consists of sections, specifying goals, budgetary interests, economic threats, including their complex monitoring methodology, security criteria and stages of activity towards ensuring fiscal stability and security.

In the authors' view, the strategic vectors for ensuring the stability and security of public budget of the Visegrad country in the current context include: establishing compliance with the rules of budgetary procedures of foreign practice of budgeting, reviewing and approving budgets at all levels; expansion of sources of forming the revenue part of budgets due to the identification of reserves and the use of alternative sources of forming of financial resources; improvement of the budget planning and forecasting system; increase of efficiency of administration and control over spending of budgetary funds; reviewing the parameters of the investigated countries' budgets in the direction of optimization of their revenues and expenditures; improving the system of intergovernmental budgetary relations; prevention of unjustified budget deficits and improvement of deficit financing of state and regional activities.

We believe that the areas of further study in the field of sustainability and security of public budget should be based on applied correlation-regression methods, because in order to achieve a significant level of state development, as a final goal of any government activity, it is necessary to determine the dependence forms of parallel changes of several aggregate features on other features, identify the features of factors' coupling, determine the factors' parameters, directions, density, materiality, as well as evaluate the reliability. Identification of causal relationships at the macro level, which determine the development of the financial system of any country, allows you to interpret the results and develop sound management decisions, which is a necessary prerequisite for effective government.

Conclusions

The study pointed out the analysis of vulnerabilities of the internal and external economy and public finances sectors, as well as risk assessment of public borrowing, based on indicators of fiscal stability and security, are important components of a successful state functioning. Ensuring the sustainable development of the Visegrad Group countries for the successful implementation of fiscal policy is due to compliance with the limits of the above-mentioned indicators.

The results of the analysis showed non-compliance with the limits of fiscal stability and security indicators (when the result of calculating the coefficient is not included in the threshold values) poses threats and additional risks to national economies of the Visegrad Group, which provokes financial instability and economic instability. (debt) crises. The study showed that important components are the analysis of the vulnerability of the internal and external sectors of the economy and public finances, as well as the risk assessment of public borrowing, conducted on the basis of stability and security of the state budget.

We believe that a comprehensive assessment of the budget system of the Czech Republic, Slovakia, Poland and Hungary based on indicators of stability and security of the state budget should help inform investors and creditors about the conditions and prospects of cooperation with the Visegrad region.

The results of the analysis of the relevant indicators will allow to give an overall assessment of the development prospects of the studied countries, to determine their potential budgetary capacity and possible financial risks, to assess the effectiveness of budget management. This will create conditions for dynamic, balanced socio-economic development of the Czech Republic, Slovakia, Poland and Hungary, which will improve the living standards of these countries, ensure compliance with social standards, as well as increase the potential of Visegrad countries, improve management decisions, improve management decisions. functioning of state and local authorities.

These indicators of stability and security of the state budget will demonstrate the level of trust in all authorities, as well as the level of government perception of public needs in general and individual needs in particular.

The authors believe the proposed system of indicators of stability and security of public budget can be supplemented by a number of additional indicators. Thereupon, it is recommended to draw up an appropriate regulatory document that will regulate the budget process, taking into account the approved methodology of sustainability and security. This legislation act shall be binding for budgetary practice and its implementation shall require reporting on the highest level.

Conflict of interest
There are no conflicts to declare.

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