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Content

MODELLING THE IMPACT OF SME LENDING ON BUSINESS VALUE ADDED

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Highlight
The paper deals with the revealing measure of the SME lending impact on its value added.

Abstract
The SME lending covers a list of its needs related to its day-to-day performance, fixed assets, development. Existing methods of identifying impact on economic indicators from using loans by SMEs are limited. The aim of the research is to develop a methodology which allows reveal the impact of SME lending on business value added on macroeconomic level. The methodology is based on correlation regression analysis in order to identify the level of loan influence on business development, value added in particular, due to the lack of adequate methods for SME development forecasting. The obtained results are sufficient for medium business and be used in forecasting medium business development in Ukraine. For small business model has insufficient density of the relationship between indicators, therefore, it was proposed to use additional factors as equity; liabilities and non-economic factors exemplified as the level of shadow economy.

Keywords
SME; lending; value added; modelling; correlation-regression analysis.

Introduction
The successful business development, SME in particular, leads to economic growth and increases the investment attractiveness of economy on national and multinational level. The main indicator which identifies the level of business development is its value added as on national as well as on sectoral level, e.g., large, medium, small. The financial potential of legal entities defines the level of a separate country economic growth and its sustainability. In the given research the financial potential of SMEs is considered as its ability to obtain loans from

credit institutions considering the level of SME sustainability and attractiveness for such institutions according to scoring systems applied by them. It is well-known, that only those SMEs, which have stable growth of economic indicators, namely revenues, profit, value added could be attractive for credit institutions as a result to obtain loans from them. That is why it is important to assess impact of loan as a factor on value added formation which can be made by using approaches of economic and mathematical modelling, in particular correlation-regression analysis.

In the research the effect of SME loan volumes` impact on its value added was defined by determination regression model, using a cubic single-factor one, separately for small and medium business. It is also possible to forecast value added volumes of SMEs on macroeconomic level using the proposed model. So, the main aim of this research is to develop a methodology based on econometric modelling which allows reveal the SME lending impact on business value added on macroeconomic level. SMEs play a critical role in economic growth and development, but often face challenges in accessing financing to support their operations and expansion, making it essential to investigate the impact of SME lending on business value added, which the literature review aims to explore in this article.

A lot of papers are dedicated to SMEs financial issues during the pandemic period: Shrivastav [1] considered finance challenges; Zhao, Matthews, & Munday studied the specifics of relations between banking and SME during borrowing process [2]; Fasth, Akerman, Elliot, & Hilmersson investigated the effect of external funding for SMEs [3]; Elshaer notes that financial resources, along with social and human resources, are critical factors that contribute to entrepreneurial resilience during times of crisis [4]; Taghizadeh-Hesary, Phoumin, & Rasoulinez suggested that measures such as regional liquidity support facilities, targeted credit guarantee schemes, and collaboration between regional development banks and private sector institutions could help to support SMEs in accessing finance and navigating the financial risks posed by the pandemic [5]. Cecere, Corrocher, Mancusi revealed that public funding is perceived by SMEs and complicated and full of bureaucracy and that was the huge obstacle on perceiving support programs by SMEs [6]. Rupeika-Apoga, Petrovska, & Bule note that digitalization can offer SMEs various benefits, including improved financial management through the use of digital financial tools and platforms [7]; Eggers notes that access to finance is often a critical challenge for SMEs during times of crisis, and that this challenge can be compounded by factors such as increased uncertainty and risk aversion among lenders [8]; Cowling, Brown, and Rocha suggested that those companies that had more cash reserves proved to be more resilient in the face of COVID-19. They also discussed the article also discusses the challenges faced by SMEs in accessing government support programs, including those related to finance, and notes that more needs to be done to ensure that these programs are accessible and effective for SMEs [9]. Recent studies in general point out the role of SMEs lending and other borrowing instruments (including regional returning back money programs) in circular economy launching [10,11] and Eniola and Entebang explored the relationship between financial innovation and SME firm performance, including the role of banks in providing financial services to SMEs [12].

Most research on SMEs development has been carried out in access to finance problem in frame support of the competitiveness and sustainable growth of SMEs and the emergence of alternative financing models, such as crowdfunding and peer-to-peer lending, and their potential impact on traditional business lending by banks [13–15]. The dependence between financial literacy and financial potential of the SMEs in general are proved by Ye & Kulathunga [16]. El-Hamid, Eissa & Radwan using case method claim that financial resources service as drivers for SMEs growth [17]. Our previous research was related to the estimation of the investment potential of the SMEs throughout of machine learning tools [18]. The effects of different innovations implementation in SMEs activities are considered by (AI instruments) [19]; big data analytics adoption by SMEs [20]. Onikienko et al considered relatedness the long-term SME projects assessment with non-standard cash flows [21]. Khovrak related the level of financial safety of the banks to the financial potential of SMEs who get loans [22]. Mints et al. considered SMEs lending as a factor of banking stability during the crises [23]. In China family SMEs tends to use traditional banking rather than FinTech solutions in means that the clients of FinTechs are innovative companies [24]. Phraknoi, Busby and Stevenson explored SMEs in the context relationality, awareness, control are the core principles that are basis for forming supply chain finance (SCF) [25].

Using transactional data and payment network–based variables Kou et al. offered to predict bankruptcy of the SMEs avoiding financial indicators [26]. Zizi, Oudgou, El Moudden reviled the determinants and predictors of SMEs' financial failure exploitering stepwise method of estimating logistic regression [27]. The decision-making process at SMEs has an impact on the capital structure and this was proved by Rao, Kumar, Madhavan

using generalised method of moments [28]. Bielialov presents a risk management framework and identifies the key risks faced by startups in the innovation sector, as well as strategies to mitigate these risks, including leveraging external financing sources such as banks [29]. However, it is essential to identify which key financial indicators and resources SMEs use for making economy competitive.

Methods

A wide range of general and special scientific research methods was used, in particular, observation, measurement, abstraction, comparative analysis. A significant part of the research was carried out on the basis of the use of statistical analysis and econometric modeling. Particularly, index analysis was conducted to reveal modern trends of SME value added and their credit volumes. Correlation-regression analysis was used in order to specify the lending volume impact on the SMEs` development. The obtained results were the basis for identifying the dependence between the specified indicators. A preliminary analysis of the exogenous variable influence on the dependent factor determined that this dependence should be modeled by a nonlinear (cubic) one-factor regression model. Correlation coefficients and the F-criterion were calculated aimed at this model verification. The impact of such indicator as lending volumes on SME development was specifically determined through the correlation regression model development. It is quite logical that, in reality, there is a fairly significant range of different sources of financing for these enterprises, the availability of which also affects their development. In addition to these financial parameters, there is a significant range of different factors that also determine the trajectories of SME functioning. However, in this research, we will mostly focus on the description of the influence of SME lending on the general business development and specify this influence in the form of an econometric model. The general method of application of correlation-regression analysis in the process of econometric models` formation is considered in formulas 1-6. For modeling real economic processes, a reality-oriented calculated cubic one-factor model is used, which has the following form (1):

$$\hat{y} = \widehat{a_0} + \widehat{a_1} * x^3 + \widehat{a_2} * x^2 + \widehat{a_3} * x \quad (1)$$

where:
y - the calculated value of the internal variable;
x - the actual values of the external variable;
a_0, a_1, a_2, a_3 - the calculated parameters of the model.

Accordingly, the error will be equal to (2):

$$\mathcal{E} = y - \hat{y} \quad (2)$$

The calculated parameters a_0, a_1, a_2, a_3 could be determined using the method of least squares. The main idea of this technique is to approximate the deviations of the calculated values to the real ones, in particular with minimal error in all possible variants (3).

$$\mathcal{E} \to min \quad (3)$$

There is some dependence, the smaller the error value, the closer the model is to the real model of the relationship between the two indicators (4):

$$\sum_{i=1}^{n} \mathcal{E} = \sum_{i=1}^{n} (y_i - \widehat{a_0} + \widehat{a_1} * x^3 + \widehat{a_2} * x^2 + \widehat{a_3} * x) \quad (4)$$

where:
$\sum_{i=1}^{n} \mathcal{E}$ - the sum of deviations y from the trend value, which describes the approximate relationship between x and y.
$\sum_{i=1}^{n} \mathcal{E}$ can take both positive and negative values. So:

$$\sum_{i=1}^{n} (y - \widehat{a_0} + \widehat{a_1} * x^3 + \widehat{a_2} * x^2 + \widehat{a_1} * x)^2 \to min \quad (5)$$

To determine the calculated parameters a_0, a_1, a_2, a_3, an essential condition is to achieve the minimum value in the regression equation. The derivatives of this function must be equal to zero to perform the minimum of function (5). The cubic one-factor model is defined by the following system of equations (6):

(6)
$$\begin{cases} a_3\sum x_i^3 + a_2\sum x_i^2 + a_3\sum x_i + na_0 = \sum y_i \\ a_3\sum x_i^4 + a_2\sum x_i^3 + a_1\sum x_i^2 + a_0\sum x_i = \sum x_i y_i \\ a_3\sum x_i^5 + a_2\sum x_i^4 + a_1\sum x_i^3 + a_0\sum x_i^2 = \sum x_i^2 y_i \\ a_3\sum x_i^6 + a_2\sum x_i^5 + a_1\sum x_i^4 + a_0\sum x_i^3 = \sum x_i^3 y_i \end{cases}$$

For modelling the impact of SME lending on business value added the open data from State Statistic Service of Ukraine, National bank of Ukraine, Banque De France were used. These data were collected and processed through Tableau Desktop software.

Results and discussion

SME development significantly depends on the factors of the economic environment, in particular on the state policy of support and stimulation, the development of infrastructure, the ease of doing business. One of the main indicators that characterizes the level of business development is its Value Added (hereinafter VA), the dynamic trends of which are presented in Figure 1 both in national and foreign currency for small and medium-sized enterprises, respectively.

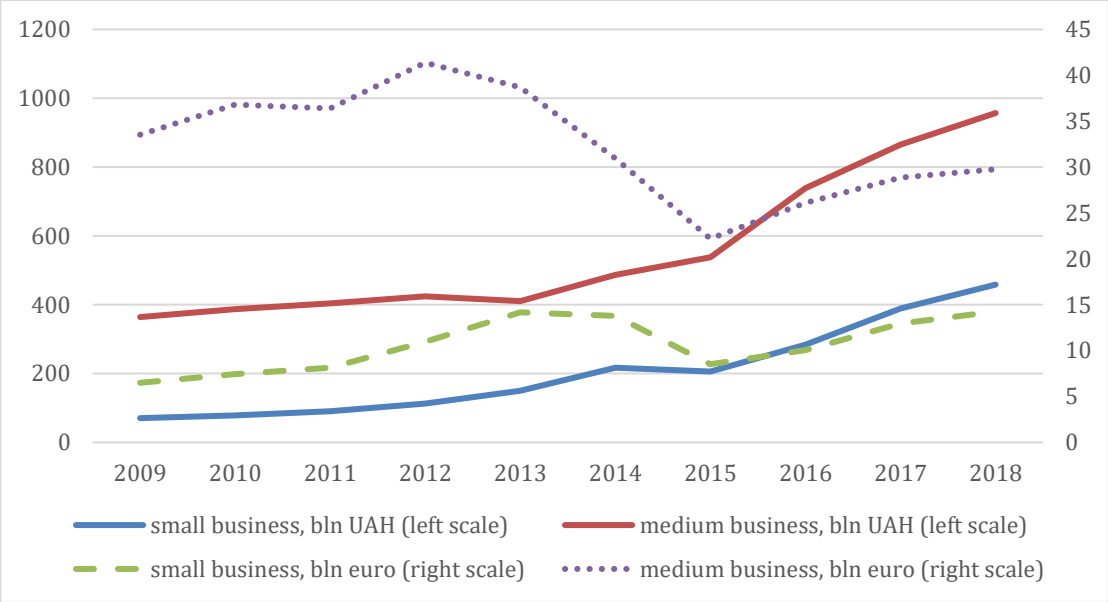


Figure 1. Dynamics of SME VA in UAH and equivalent of euro. *Source: Calculations based on [30–33].*

Bringing the level of VA to the equivalent of euro shows that its growth rate is much lower compared to the same indicator in the UAH equivalent, for both enterprise types. The difference in growth rates for 2014 and 2015 is especially noticeable:

- for small business: in the UAH equivalent the growth rate for 2014 was 44% and in the euro equivalent the rate of VA decrease was 3%; for 2015 the rate of decline in UAH was 5% and in euro equivalent about 38%.
- for medium business: the growth rate in 2014 compared to 2013 in hryvnia was 18% and in euro the rate of decrease was 20%; in 2015 the growth rate was 10.6% in hryvnia equivalent, while in the euro the rate of decrease was about 28%.

Regarding the mentioned period of 2014-2015, the economy of Ukraine was characterized by significant inflation, which explains the significant lag in the rate of SME VA change in national and foreign currency. For 2016, both small and medium business were characterized by the same trends, namely the excess of the UAH

growth rate over the euro value by 20% and for 2017 this value was 7.8% and 6.7% for small and medium business, respectively; for 2018 - 7.8% and 7.4%. The period 2009 - 2013 was characterized by opposite trends in excess of the level of growth in euro equivalent over UAH equivalent, which indicates a higher level of business protection at the national level in terms of currency risks.

This exacerbation of inflation and currency risks did not promote business development and reduced their potential attractiveness to financial institutions in regard to obtain loans by legal entities. As well known, financial security plays a significant role in enhancing the SME sector and strengthening its capacity. So, the identification of lending to VA ratio in Ukraine and comparison with European countries, namely Austria, Belgium, Croatia, Germany, France, Italy, Spain, Poland, Portugal and Slovakia, is appropriate to determine the thresholds that indicate the level of infrastructure. The analysis was conducted separately for small and medium business (Figure 2 and 3).

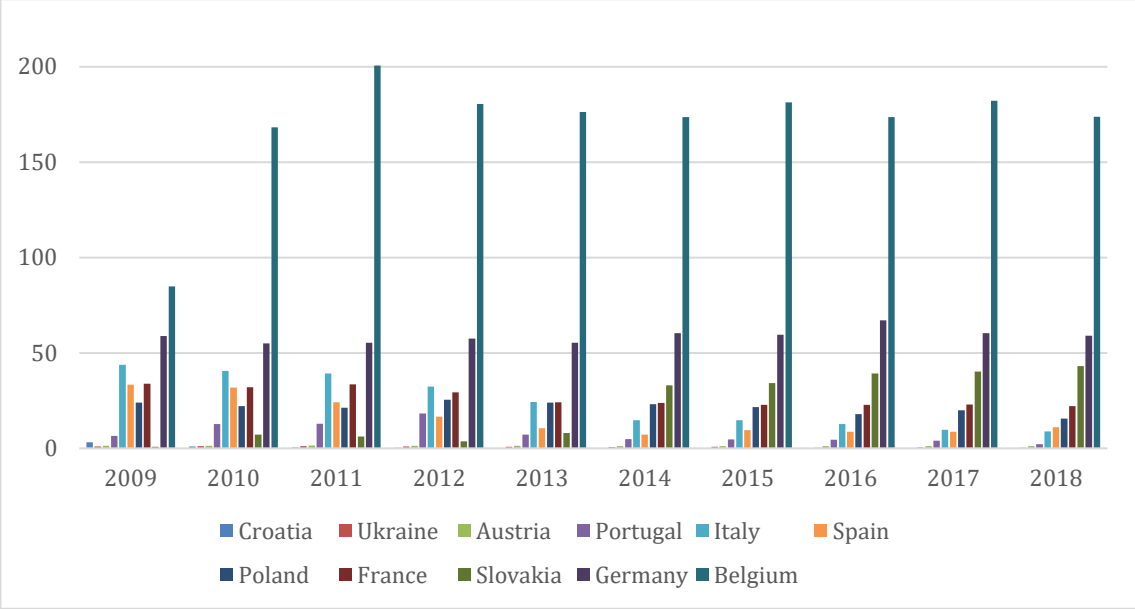


Figure 2. The ratio of loans attracted by small business to the total amount of value added, units. *Source: Calculations based on [31–34].*

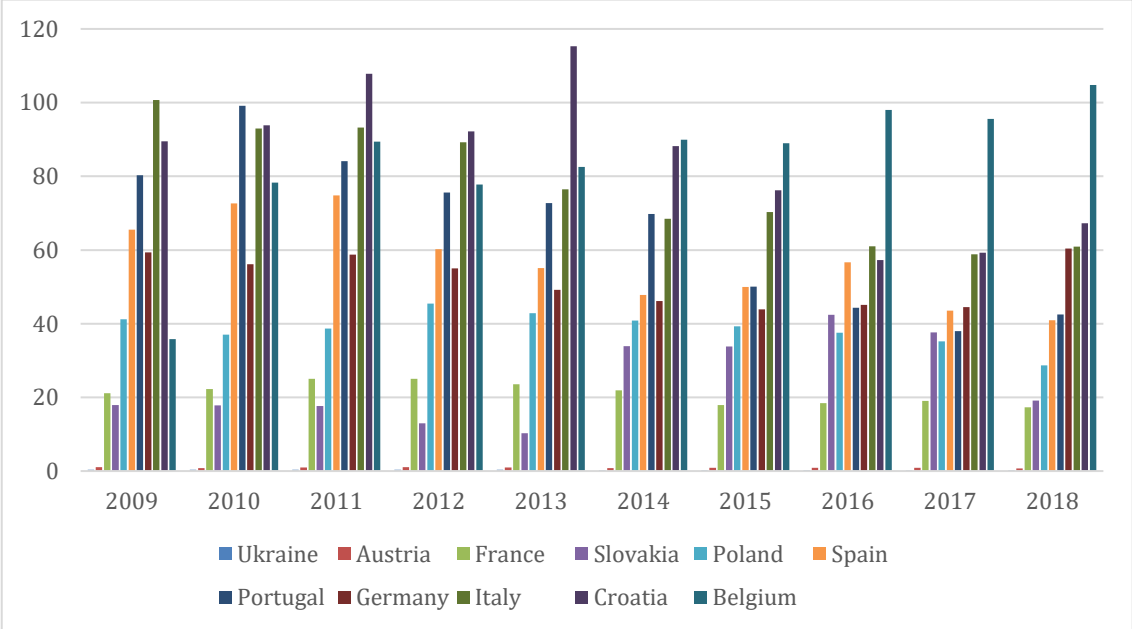


Figure 3. The ratio of loans raised by medium business to the total value-added units. *Source: Calculations based on [31–34].*

According to the calculated ratios, small business in Croatia and Ukraine is characterized by the lowest level of loans with an average for the period 2009-2018 of 0.5 and 0.7 respectively. The majority of the considered European countries have this indicator at a higher level (from 10 and above). Belgium, Germany, Slovakia and France have the highest ratios for small business, averaging 170; 59; 37 and 27 respectively, which indicates a high level of credit security for this type of enterprises. This fact may also be connected with the developed financial infrastructure and the willingness of financial institutions to lend to small business, as well as the appropriate level of state support and incentives in terms of loan guarantees, preferential interest rates and more. According to the calculations of this ratio for medium business, its values are much higher than for small ones in selected countries, which is explained by the higher level of financial stability of the entities in this sector. The exception is the value for Ukraine, which on average for 2009 - 2018 is 0.3. Austria, France and Slovakia have the lowest ratios in Europe, averaging 0.9; 21.1 and 24.3 respectively and the highest - Belgium, Croatia, Italy and Germany, which have an average ratio of 84.1; 84.7; 77.2 and 51.8 respectively. Given that most European countries have a sufficient level of credit ratio to VA, in contrast to Ukraine, it can be argued that there is a higher level of SME financial security in European countries. However, the different level of lending in the same country depending on the sector (small or medium business) is primarily related to the existing business support policy in the country.

Given the above, in order to deepen the understanding of the peculiarities of SME VA in Ukraine and find the relevant mechanisms to ensure its financing, it is advisable to carry out economic and mathematical modelling to identify dependence level between financial security and VA. Using the formula 6, we will determine the impact of changes in the volume of small business lending on the amount of its VA. Thus, using the appropriate analytical and statistical data, we determine the parameters a_0, a_1, a_2, a_3 based on the data of intermediate calculations (Annex A).

The coefficients a, b, c and d of the cubic regression equation $\hat{y} = ax^3 + bx^2 + cx + d$ determined from the system of equations, solved by the Cramer method (see details in the Annex B). Therefore, the initial cubic regression equation has the form:

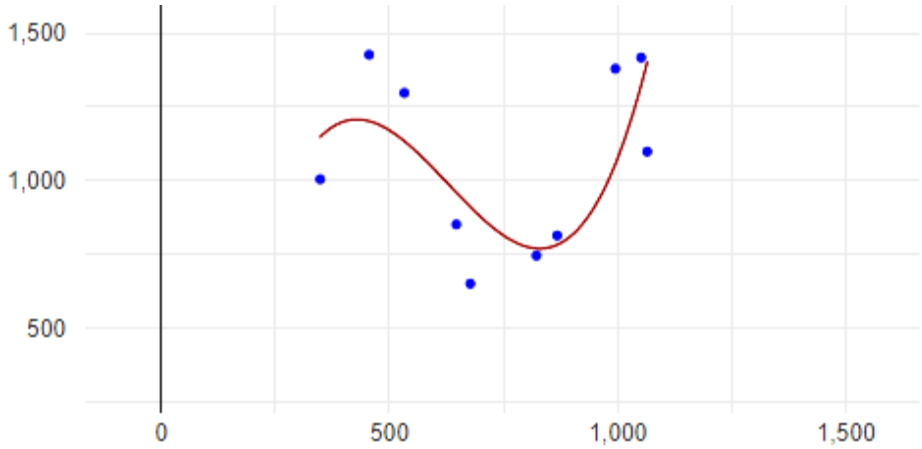
(7) $$\hat{y} = 0.0257x^2 + 14.5489x - 1375.2277$$

As a result of the relevant calculations, we obtain the following regression equation of the correlation between the volume of obtained loans by small business and its value added in Ukraine.

(8) $$VA_{SE} = -0.02Cr_{SE}^2 + 14.55Cr_{SE} - 1375.23$$

where:
VA_{se} - the volume of small business value added.
CR_{se} - the amount of small business loans.

The graphically illustrated dependence is presented in Figure 4.



R^2=0.7195

F^{fact}=2.146

$F^{fact} < F^{tabl.}$

Figure 4. The relationship between the amount of lending and the added value of small business. *Source: Calculations based on [31–33].*

According to the correlation-regression analysis methodology, it is relevant to assess the adequacy of the obtained dependence. The estimation is conducted based on determining such indicators as correlation coefficient, coefficient of determination and Fisher's criterion.

The correlation coefficient determines the level (closeness) of the relationship between the two indicators and shows the level of influence of the independent variable on the dependent one. This indicator is determined by the formula (9):

$$R = \sqrt{1 - \frac{\sum(y_i - \widehat{y_i})^2}{\sum(y_i - \overline{y_i})^2}}, \quad (9)$$

where:
y_i - the actual values of the dependent variable.
$\widehat{y_i}$ - estimated values of the dependent variable.
$\overline{y_i}$ - the average value of the estimated values of the dependent variable.

The coefficient of determination shows the effect of the dependent variable change on the independent value and is defined as the square of the correlation coefficient. To evaluate econometric models for adequacy it is feasible to use Fisher's criterion, which is determined by the following formula (10):

$$F = \frac{R^2}{1 - R^2} * \frac{n - k}{k - 1} \quad (10)$$

where:
R^2 - the coefficient of determination.
n - the number of observations.
k - the number of parameters of the evaluation model.
m - the number of factors in the regression equation.

To analyse the calculated value of the Fisher criterion, it is necessary to compare it with the tabular index for a certain conditional error. If Ffact > Ftable, the defined regression model is significant and corresponds as closely as possible to the actual functioning model. To determine the quantitative value of the parameters by which you can check the econometric models for adequacy, additional calculations should be performed, the results of which are presented in Annex A.

The correlation coefficient to verify the model adequacy for small business is calculated as follows:

$$R = \sqrt{1 - \frac{\sum(y_i - \widehat{y_i})^2}{\sum(y_i - \overline{y_i})^2}} = \sqrt{1 - \frac{383685.9721}{795389.1174}} \approx 0.7195 \quad (11)$$

Thus, the relationship between the two parameters for small business is not strong enough, because the approximation of the correlation coefficient indicates that small business VA depends on the loan volumes, but not enough. However, the outlined relationship is logical, so it requires further research and consideration of additional factors when modelling of small business VA. The coefficient of determination is equal to:

$$R^2 = 0.7195^2 \approx 0.5176 \quad (12)$$

This means that approximately 51.76% of small business lending affects the amount of its VA. Fisher's F-criteria are defined as follows:

- Critical (tabular):

$$F_{tabl} = F(a, k_1, k_2 = F(0.05,3,6) \approx 4.7571 \quad (13)$$

- Fact:

(14) $$F_{fact} = \frac{R^2}{1-R^2} * \frac{k_2}{k_1} = \frac{0.5176}{1-0.5176} * \frac{6}{3} \approx 2.146$$

- Since:

(15) $$k_1 = m = 3, k_2 = n - m - 1 = 10 - 3 - 1 = 6, a = 0.05$$

where:
m - the number of parameters for the variables of the regression equation.

Since Ffakt < Ftabl, it can be argued that the constructed regression model is not significant enough and does not correspond to reality. Thus, the calculated values of the correlation and determination coefficients, as well as Fisher's F test confirmed that this model should consider additional factors of influence for small business. For medium business, it is also advisable to design a model of the interdependence of value added on lending. A system of equations constructed because of algebraic transformations can be solved using the Cramer method.

As a result of the relevant calculations, we obtain the following equation between the volume of obtained loans by medium business and its VA in Ukraine.

(16) $$VA_{Me} = -0.08Cr_{Me}^2 + 8.15Cr_{Me} - 75.66$$

where:
VA_{ME} - the volume of medium business value added.
CR_{ME} - the amount of loans of medium business.

Therefore, the initial cubic regression equation has the form:

(17) $$\hat{y} = -0.008x^2 + 8.15x - 75.66$$

This dependence can be graphically illustrated in Figure 5. The results of additional calculations (the quantitative value of the parameters) for medium business to check the econometric models for adequacy are presented in Annex A.

The calculated correlation coefficient for checking the adequacy of the model for medium business lending impact on its VA in Ukraine is as follows:

(18) $$R = \sqrt{1 - \frac{\sum(y_i - \hat{y_i})^2}{\sum(y_i - \bar{y})^2}} = \sqrt{1 - \frac{356960.3371}{3219290.4764}} \approx 0.9429$$

Thus, there is a strong relationship between the two parameters for medium business. This suggests that the amount of VA strongly depends on lending. The outlined relationship is logical and such a close correlation indicates the significant importance of financial security in the development of medium business (Annex C).

The coefficient of determination is equal to:

(19) $$R^2 = 0.9429^2 \approx 0.8891$$

This means that approximately 88.91% of the lending volumes of medium business affects the amount of its value added.
Fisher's F-criteria are defined as follows:

- Critical (tabular):

(20) $$F_{tabl} = F(a, k_1, k_2) = F(0.05, 3, 6) \approx 4.7571$$

- Fact:

(21) $$F_{fakt} = \frac{R^2}{1 - R^2} \cdot \frac{k_2}{k_1} = \frac{0.8891}{1 - 0.8891} \cdot \frac{6}{3} \approx 16.0372$$

Since $F_{fakt} > F_{tabl}$, it can be argued that the constructed regression model is significant and true. Thus, the calculated values of the correlation coefficients, determination and Fisher's F-test allow to confirm the correctness of the defined model.

According to the obtained simulation results, it was found that there is a close relationship between the lending volume and the medium business VA (R^2 = 0.91), i.e., the growth of lending to the sector leads to an increase in business VA. At the same time, for small business there is an insufficient level of adequacy of the relationship between the volume of lending and business value added (R^2 = 0.71), which causes the expansion of the list of factors influencing the VA of small business.

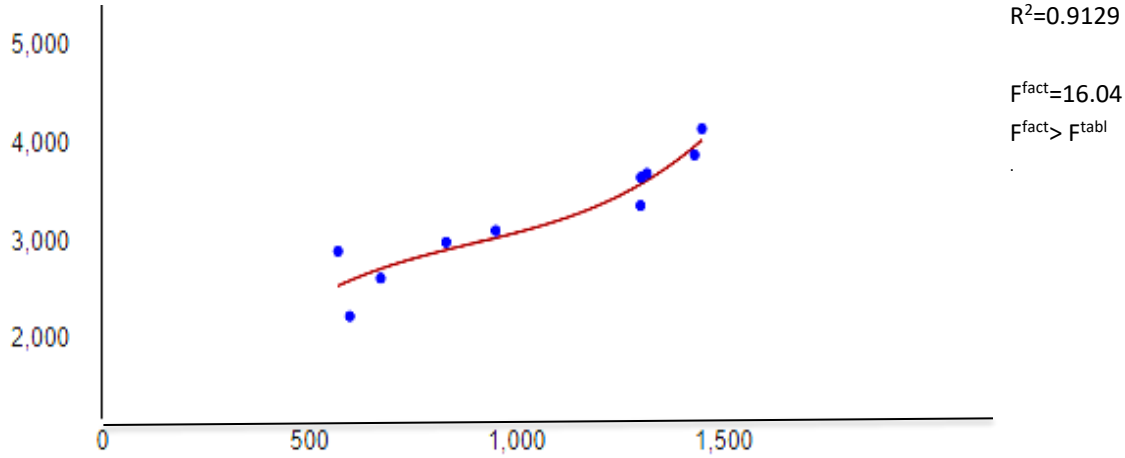


Figure 5. The relationship between the volume of lending and the value added of medium business. *Source: Calculations based on [31–33].*

Impact

The developed model is mainly aimed at value added identification for SMEs. SME sector plays the pivotal role in economic development of every country as well as in the employment level which identifies general social welfare and economic stability. It is well-known that business value added is one of the main indicators of financial solvency and profitability. Though it is important to have adequate methodic to forecast value added considering specific features of SMEs.The obtained results of SME value added modelling based on the impact of the loan volume can be used in forecasting the financial and investment potential on macroeconomic level. It could be useful not only for SMEs, but also for policymakers on macro and local level to forecast value added in SME sector and develop the adequate support policies (loan guarantees, soft loans, government loans, others) to business needs.

Conclusions

The obtained results of modeling of SME VA based on the impact of the loan volume can be used in forecasting the financial and investment potential on macroeconomic level. However, the insufficient density of the relationship between the volume of lending and VA for small business suggests the need to use the expanded list of influencing factors, in particular, it is proposed the following factors: equity; short-term liabilities; long-term liabilities. The designed model for medium business can be used in forecasting its development in Ukraine. It can also be argued that greater development of financial infrastructure, ensuring policies to promote SME development, including loan guarantees, soft loans, government loans are able to increase the VA of medium business in Ukraine. It is determined that it is necessary to consider the data of non-economic impact (shadow financial flows, information asymmetry, underdeveloped infrastructure, and other factors) in forecasting the value added of small business in Ukraine, which is confirmed by the results

of regression-correlation analysis. The obtained results can be a basis for quantifying the level of dependence between the level of lending and the value added of small business in Ukraine and to consider the indicator of the "shadow" sector. Further research will be devoted to the methodology development of the integrated indicator regarding shadow level of small business identification to forecast and modelling its development.

Conflict of interest

There are no conflicts to declare.

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Annex A

Table 1. Intermediate calculations to find the dependence equation between the volume of lending and the volume of its value added. *Source: Author.*

i	x_i	y_i	x_i^2	x_i^3	x_i^4	x_i^5	x_i^6	x_iy_i	$x_i^2y_i$	$x_i^3y_i$
Small business										
1	677.393	650.051	458861.2764	310829416.6376	210553671024.4057	142627582876235.25	96614926247281630	440339.997	298283231.6169	202054973114.6999
2	822.277	745.249	676139.4647	555973930.639	457164575764.0188	375915915865510.1	309070011550144060	612801.112	503892259.9498	414339015834.7604
3	867.61	813.45	752747.1121	653090921.9291	566628214774.89	491612305420842.3	426527752306177000	705757.3545	612322138.3377	531256810443.2111
4	1064.751	1098.114	1133694.692	1207102557.0028	1285263654671.2424	1368485761574860	1457096583122593800	1169217.9796	1244926013.012	1325536217280.5254
5	1051.508	1417.021	1105669.0741	1162619876.7309	1222504101341.5432	1285472842593443.5	1351684977769746700	1490008.9177	1566756296.9992	1647456780345.0806
6	995.128	1379.179	990279.7364	985455093.5083	980653956292.7646	975876210217706.2	971121741321525800	1372459.6399	1365773016.5463	1359118970409.735
7	646.786	850.96	418332.1298	270571364.9022	175001770819.6573	113188695341362.88	73208863505058720	550389.0146	355983909.1712	230245408677.2064
8	348.64	1004.311	121549.8496	42377139.5645	14774365937.7826	5150934940548.531	1795821957672839.8	350142.987	122073851.0016	42559827413.2067
9	532.936	1297.187	284020.7801	151364898.4612	80667803526.3404	42990776540113.766	22911332486182070	691317.651	368428063.6704	196348578540.243
10	455.866	1426.469	207813.81	94735250.2894	43186579608.4285	19687293299775.86	8974767647395622	650278.7172	296439957.6741	135136897745.0728
∑	7462.895	10681.991	6149107.9252	5434120449.6651	5036398693761.073	4821008318670400	4719043777913778000	8032713.3705	6734878737.9794	6084053479803.742
Medium business										
1	677.393	650.051	910.3445	−418.1481	174847.8335	−260.2935	67752.7043	0.4004	—	—
2	822.277	745.249	769.4438	−322.9501	104296.7671	−24.1948	585.3859	0.0325	236.0987	55742.6179
3	867.61	813.45	781.7772	−254.7491	64897.104	31.6728	1003.1671	0.0389	55.8676	3121.1847
4	1064.751	1098.114	1400.6227	29.9149	894.9012	−302.5087	91511.5402	0.2755	−334.1816	111677.3135
5	1051.508	1417.021	1322.6444	348.8219	121676.7179	94.3766	8906.9459	0.0666	396.8854	157517.99
6	995.128	1379.179	1056.1698	310.9799	96708.4982	323.0092	104334.9195	0.2342	228.6325	52272.8411
7	646.786	850.96	959.0824	−217.2391	47192.8266	−108.1224	11690.4476	0.1271	−431.1315	185874.4017
8	348.64	1004.311	1147.1131	−63.8881	4081.6893	−142.8021	20392.4388	0.1422	−34.6797	1202.6832
9	532.936	1297.187	1133.5878	228.9879	52435.4583	163.5992	26764.685	0.1261	306.4013	93881.7297
10	455.866	1426.469	1201.2053	358.2699	128357.3212	225.2637	50743.7378	0.1579	61.6645	3802.5164
∑	—	—	—	—	795389.1174	—	383685.9721	1.6014	—	665093.2782

Table 2. Additional data to determine the correlation coefficients, determination and F-criterion index. *Source: Calculations based on [31–33].*

i	x_i	y_i	$\hat{y}_i$	$y_i - y$	$(y_i - y)^2$	ε_i	ε_i^2	A_i	$\Delta\varepsilon_i$	$(\Delta\varepsilon_i)^2$
Small business										
1	677.393	650.051	910.3445	−418.1481	174847.8335	−260.2935	67752.7043	0.4004	—	—
2	822.277	745.249	769.4438	−322.9501	104296.7671	−24.1948	585.3859	0.0325	236.0987	55742.6179
3	867.61	813.45	781.7772	−254.7491	64897.104	31.6728	1003.1671	0.0389	55.8676	3121.1847
4	1064.751	1098.114	1400.6227	29.9149	894.9012	−302.5087	91511.5402	0.2755	−334.1816	111677.3135
5	1051.508	1417.021	1322.6444	348.8219	121676.7179	94.3766	8906.9459	0.0666	396.8854	157517.99
6	995.128	1379.179	1056.1698	310.9799	96708.4982	323.0092	104334.9195	0.2342	228.6325	52272.8411
7	646.786	850.96	959.0824	−217.2391	47192.8266	−108.1224	11690.4476	0.1271	−431.1315	185874.4017
8	348.64	1004.311	1147.1131	−63.8881	4081.6893	−142.8021	20392.4388	0.1422	−34.6797	1202.6832
9	532.936	1297.187	1133.5878	228.9879	52435.4583	163.5992	26764.685	0.1261	306.4013	93881.7297
10	455.866	1426.469	1201.2053	358.2699	128357.3212	225.2637	50743.7378	0.1579	61.6645	3802.5164
∑	—	—	—	—	795389.1174	—	383685.9721	1.6014	—	665093.2782
Medium business										
1	1299.624	3351.906	3569.4801	105.3656	11101.9097	−217.5741	47338.5051	0.0649	—	—
2	1314.661	3679.257	3607.2358	432.7166	187243.6559	72.0212	5187.0468	0.0196	289.5953	83865.4335
3	1300.444	3639.469	3571.4968	392.9286	154392.8847	67.9722	4620.2181	0.0187	−4.049	16.3942
4	1447.859	4137.335	4021.795	890.7946	793515.0194	115.54	13349.4975	0.0279	47.5678	2262.6993
5	1429.85	3869.597	3956.5283	623.0566	388199.5268	−86.9313	7557.046	0.0225	−202.4713	40994.6262
6	949.852	3095.896	3021.1173	−150.6444	22693.7353	74.7787	5591.8472	0.0242	161.7099	26150.1003
7	597.67	2220.324	2583.9327	−1026.2164	1053120.0996	−363.6087	132211.3219	0.1638	−438.3874	192183.5149
8	672.326	2609.713	2705.4052	−636.8274	405549.1374	−95.6922	9156.989	0.0367	267.9166	71779.2997
9	569.138	2884.67	2530.1019	−361.8704	130950.1864	354.5681	125718.5171	0.1229	450.2602	202734.2735
10	830.24	2977.237	2898.3108	−269.3034	72524.3213	78.9262	6229.3485	0.0265	−275.6418	75978.4289
∑	—	—	—	—	3219290.4764	—	356960.3371	0.5276	—	695964.7704

Annex B

(1) $$\begin{cases} a\sum x_i^3 + b\sum x_i^2 + c\sum x_i + nd = \sum y_i, \\ a\sum x_i^4 + b\sum x_i^3 + c\sum x_i^2 + d\sum x_i = \sum x_i y_i, \\ a\sum x_i^5 + b\sum x_i^4 + c\sum x_i^3 + d\sum x_i^2 = \sum x_i^2 y_i, \\ a\sum x_i^6 + b\sum x_i^5 + c\sum x_i^4 + d\sum x_i^3 = \sum x_i^3 y_i, \end{cases} \leftrightarrow \begin{cases} 5434120449.6651a + 6149107.9252b + 7462.895c + 10d = 10681.991, \\ 5036398693761.073a + 5434120449.6651b + 6149107.9252c + 7462.895d = 8032713.3705, \\ 4821008318670400a + 5036398693761.073b + 5434120449.6651c + 6149107.9252d = 6734878737.9794, \\ 4719043777913778000a + 4821008318670400b + 5036398693761.073c + 5434120449.6651d = 6084053479803.742 \end{cases}$$

(2) $$\Delta = \begin{vmatrix} 5434120449.6651 & 6149107.9252 & 7462.895 & 10 \\ 5036398693761.073 & 5434120449.6651 & 6149107.9252 & 7462.895 \\ 4821008318670400 & 5036398693761.073 & 5434120449.6651 & 6149107.9252 \\ 4719043777913778000 & 4821008318670400 & 5036398693761.073 & 5434120449.6651 \end{vmatrix} = 1.0340950915396628e + 32$$

(3) $$\Delta a = \begin{vmatrix} 10681.991 & 6149107.9252 & 7462.895 & 10 \\ 8032713.3705 & 5434120449.6651 & 6149107.9252 & 7462.895 \\ 6734878737.9794 & 5036398693761.073 & 5434120449.6651 & 6149107.9252 \\ 6084053479803.742 & 4821008318670400 & 5036398693761.073 & 5434120449.6651 \end{vmatrix} = 1.4098769082675717e + 27 \Longrightarrow a$$

(4) $$a = \frac{\Delta a}{a} = \frac{1.4098769082675717e + 27}{1.0340950915396628e + 32} \approx 0$$

(5) $$\Delta b = \begin{vmatrix} 5434120449.6651 & 10681.991 & 7462.895 & 10 \\ 5036398693761.073 & 8032713.3705 & 6149107.9252 & 7462.895 \\ 4821008318670400 & 6734878737.9794 & 5434120449.6651 & 6149107.9252 \\ 4719043777913778000 & 6084053479803.742 & 5036398693761.073 & 5434120449.6651 \end{vmatrix} = -2.66097556361248e + 30 \Longrightarrow b$$

(6) $$b = \frac{\Delta b}{b} = \frac{-2.660975563612448e + 30}{1.0340950915396628e + 32} \approx -0.0257$$

(7) $$\Delta c = \begin{vmatrix} 5434120449.6651 & 6149107.9252 & 10681.991 & 10 \\ 5036398693761.073 & 5434120449.6651 & 8032713.3705 & 7462.895 \\ 4821008318670400 & 5036398693761.073 & 6734878737.9794 & 6149107.9252 \\ 4719043777913778000 & 4821008318670400 & 6084053479803.742 & 5434120449.6651 \end{vmatrix} = 1.5044993446049503e + 33 \Longrightarrow c$$

(8) $$c = \frac{\Delta c}{c} = \frac{1.5044993446049503e + 33}{1.0340950915396628e + 32} \approx 14.5489$$

(9) $$\Delta d = \begin{vmatrix} 5434120449.6651 & 6149107.9252 & 7462.895 & 10681.991 \\ 5036398693761.073 & 5434120449.6651 & 6149107.9252 & 8032713.3705 \\ 4821008318670400 & 5036398693761.073 & 5434120449.6651 & 6734878737.9794 \\ 4719043777913778000 & 4821008318670400 & 5036398693761.073 & 6084053479803.742 \end{vmatrix} = -1.4221162020857555e + 35 \Longrightarrow d$$

(10) $$d = \frac{\Delta d}{d} = \frac{-1.4221162020857555e + 35}{1.0340950915396628e + 32} \approx -1375.2277$$

Annex C

(1)
$$\begin{cases} a\sum x_i^3 + b\sum x_i^2 + c\sum x_i + nd = \sum y_i, \\ a\sum x_i^4 + b\sum x_i^3 + c\sum x_i^2 + d\sum x_i = \sum x_i y_i, \\ a\sum x_i^5 + b\sum x_i^4 + c\sum x_i^3 + d\sum x_i^2 = \sum x_i^2 y_i, \\ a\sum x_i^6 + b\sum x_i^5 + c\sum x_i^4 + d\sum x_i^3 = \sum x_i^3 y_i, \end{cases} \leftrightarrow \begin{cases} 14755957504.0559a + 11973944.4115b + 104115.664c + 10d = 32465.404, \\ 19000231983943.36a + 14755957504.0559b + 11973944.4115c + 10411.664d = 35585178.2969, \\ 25134040398632910a + 19000231983943.36b + 14755957504.0559c + 11973944.4115d = 42512235496.7012, \\ 33809438665908510000a + 25134040398632910b + 19000231983943.36c + 14755957504.0559d = 53746960697724.61 \end{cases}$$

(2)
$$\Delta = \begin{vmatrix} 14755957504.0559 & 11973944.4115 & 10411.664 & 10 \\ 19000231983943.36 & 14755957504.0559 & 11973944.4115 & 10411.644 \\ 25134040398632910 & 19000231983943.36 & 14755957504.0559 & 11973944.4115 \\ 33809438665908510000 & 25134040398632910 & 19000231983943.36 & 14755957504.0559 \end{vmatrix} = 1.817588096446771e + 33$$

(3)
$$a = \begin{vmatrix} 32465.404 & 11973944.4115 & 10411.664 & 10 \\ 35585178.2969 & 14755957504.0559 & 11973944.4115 & 10411.644 \\ 42512235496.7012 & 19000231983943.36 & 14755957504.0559 & 11973944.4115 \\ 53746960697724.61 & 25134040398632910 & 19000231983943.36 & 14755957504.0559 \end{vmatrix} = 3.494444939093879e + 27 \Longrightarrow a$$

(4)
$$a = \frac{\Delta a}{a} = \frac{3.494444939093879e + 27}{1.8117588096446771e + 33} \approx 0$$

(5)
$$\Delta b = \begin{vmatrix} 14755957504.0559 & 32465.404 & 10411.664 & 10 \\ 19000231983943.36 & 35585178.2969 & 11973944.4115 & 10411.664 \\ 25134040398632910 & 42512235496.7012 & 14755957504.0559 & 11973944.4115 \\ 33809438665908510000 & 53746960697724.61 & 19000231983943.36 & 14755957504.0559 \end{vmatrix} = -9.399670927024799e + 30 \Longrightarrow b$$

(6)
$$b = \frac{\Delta b}{b} = \frac{-9.399670927024799e + 30}{1.8117588096446771e + 33} \approx -0.008$$

(7)
$$\Delta c = \begin{vmatrix} 14755957504.0559 & 11973944.4115 & 32465.404 & 10 \\ 19000231983943.36 & 14755957504.0559 & 35585178.2969 & 10411.664 \\ 25134040398632910 & 19000231983943.36 & 42512235496.7012 & 11973944.4115 \\ 33809438665908510000 & 25134040398632910 & 53746960697724.61 & 14755957504.0559 \end{vmatrix} = 9.628393262594711e + 33 \Longrightarrow c$$

(8)
$$c = \frac{\Delta c}{c} = \frac{9.628393262594711e + 33}{1.8117588096446771e + 33} \approx 8.1475$$

(9)
$$\Delta d = \begin{vmatrix} 14755957504.0559 & 11973944.4115 & 10411.664 & 32465.404 \\ 19000231983943.36 & 14755957504.0559 & 11973944.4115 & 35585178.2969 \\ 25134040398632910 & 19000231983943.36 & 14755957504.0559 & 42512235496.7012 \\ 33809438665908510000 & 25134040398632910 & 19000231983943.36 & 53746960697724.61 \end{vmatrix} = -8.940621789553508e + 34 \Longrightarrow d$$

(10)
$$d = \frac{\Delta d}{d} = \frac{-8.940621789553508e + 34}{1.8117588096446771e + 33} \approx -75.6552$$

A BRIEF OVERVIEW OF THE USE OF ADDITIVE MANUFACTURING OF CONCREATE MATERIALS IN CONSTRUCTION

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Highlights

- 3D printing is becoming more and more popular in construction industry up to architectural design to building performance.
- 3D printing brings a lot of advantages in the construction industry, for instance: low labour costs, less waste, and high efficiency.
- Material design for 3D printing is important element for efficiency of this technology.
- 3D printing requires development and optimization for further construction application.

Abstract
Currently, additive technology is becoming increasingly popular in different areas, including its applications in construction industry. The main aim of the chapter is to show the selected applications of 3D printing technology in the construction industry and the usage of this technology on distinct stages of a construction project, from architectural design to performance of residential buildings and other civil engineering constructions. The chapter is based on a critical analysis of the literature sources, as well as the authors' experiences. The data collected are supported by selected case studies from five projects. The main findings show that 3D printing brings a lot of advantages in the construction industry, for instance: low labour costs, less waste, and high efficiency, but it still requires development and optimization.

Keywords
construction industry; additives technology; 3D printing; geopolymer.

Introduction

Additive manufacturing (also popularly called 3D printing) is a production process during which a solid 3D object is created from a numerical model by developing layers. Nowadays, this technology is gaining popularity in different industries, for example, automotive, medicine, education, etc. [1,2] Nowadays, interest in this technology is also emerging from the construction industry [3,4].

Additive manufacturing could bring many benefits to the construction industry. It could offer novel possibilities in this sector, including improving geometrical flexibility of buildings, minimalization the cost of labour, enhancement safety and improvement efficiency, as well as possibility to work in new, harsh environments and also better sustainability of the constructions [5,6]. From an architectural point of view, flexibility is a very important feature. It allows for better creativity and the design of more complex forms and shapes, including curvilinear ones. It helps with more sophisticated and aesthetic design, fulfilling the mechanical requirements. Additionally, optimized topologies allow for cost reduction because of material efficiency [7,8]. Additive manufacturing technologies also make it easier to produce individually designed elements for residential houses as well as public buildings, at the same price as the 'standard' one. It is important not only because of aesthetic requirements, but it could also significantly influence functionality, including the specific needs of people with disabilities [9,10].

Other advantages are reduction of labour costs as well as improvement of efficiency and safety of the building process. The additive manufacturing technologies minimize the manpower involved in the production process through automated manufacturing [8,11]. These technologies also have high cost-effectiveness and present high precision of execution of building elements. In the same time, they have a low-unit on-demand manufacturing compared to traditional ones [4,11]. The main reason is the reduction of additional elements, including forms, shuttering and other elements of formwork [7]. Another important element of additive manufacturing technologies is the possibility of construction in harsh environments such as subarctic climate or in-space applications; some tests have been provided for shelters on the Moon [12–14]. Finally, the sustainability of this technology is an essential element [4,11]. Effectively reduces waste, including formwork construction wastage. It means that a low amount of material can be applied for different operations, such as moulding and casting. Using these technologies, the environmental impact is limited and the carbon footprint is reduced (by minimizing inefficiencies during the building process, transportation, etc.) [6,7,15]. Regrettably, the full exploitation of additive technologies in the construction industry is currently constrained [4,11]. One of the most critical challenges of these technologies is the availability of suitable materials, especially dedicated to the large-format 3D printer [15–17]. Another challenge is related to post-processing procedures, which on a large scale are difficult to apply on a practical basis [18]. The article presents the application of additive technologies in the construction industry, including applied technologies, materials, and case studies of the practical applications. Finally, it presents the state-of-art in this new, promising area.

The use of 3D printing in building design

3D printing technology, apart from being used in construction, is also very often used in architecture, for example to create spatial models and mock-ups. It is a method that increases architects' creativity and competitive advantage by quickly creating printed models of houses and even entire estates [19]. Thanks to this technology, it is possible to develop various illustrative versions and spatial variants. The benefits it brings are enormous [19,20]. The 3D printing very faithfully reflects the technical design. The models are more durable and made in much shorter time than those obtained with the traditional method. In addition to conventional and cubature buildings, 3D models are used to design other engineering constructions, for example, bridges. Due to this, it is possible to verify the accuracy and eliminate potential errors in the design stage [21,22]. The application of 3D printing technologies in this case allows for, i.e. [19]:

- Transformation of three-dimensional digital sketches and CAD models into spatial models;
- Visualization and communication of design ideas to others;
- Study and experiment with various complex shapes;
- Reuse of projects and their components;
- More time dedicated to coming up with different project concepts;
- Doing something else while the 3D printer produces a model that is more illustrative than the computer visualizations currently being used.

The benefits of 3D printing technology for architects are invaluable. They can, for example, display faithful architectural reconstructions. It is already certain that 3D printers are gaining more and more importance as

a tool of architects and the architectural and related industries [23,24]. Printers provide the possibility of presenting alternatives of various design versions on a physical model, the use of precise working mock-ups, or multiple replications of the model for each of the consultation participants or the project team [23,25].

The typical architectural design using additive manufacturing has several steps [23,26]. Firstly, the virtual model built in a CAD program is not suitable for printing. It is related to the recording format and the modelling method. Despite the fact that the formats from AutoCAD or 3ds Max are relatively easy to export and save in a format that allows 3D printing, the solid may be corrupted during the export and it will be necessary to repair it. The flaws of the created models are all kinds of imperfections, especially leaks and overlapping lumps. Next, a digitally built model may be interpreted by the software as unprintable. Finally, manufacturers of software for 3D printers have created solutions to automate the repair process and check models for printing [23,25].

Printing technology for civil engineering constructions

3D printing technologies are finding more and more supporters in construction [27,28]. They use not only conventional construction materials, but there are also developed non-standard materials for construction occurring locally, e.g., sand in the Sahara Desert or regolith dust on the Moon.

Additionally, the designed solutions allow the printing of sewage pipes and electrical cables [19]. When it comes to efficiency, it is estimated that building with 3D printing technology gives us 35-50% shorter construction time, 30-50% lower costs, and fewer accidents during construction [29]. Selected benefits/advantages and disadvantages of using 3D printing technology in construction are presented in Table 1.

Table 1. Selected advantages and disadvantages of using 3D printing technology in construction. *Source: [7,28]*

Benefits of using 3D printing in construction	**Disadvantages of using 3D printing in construction**
Increased safety on the construction site	High financial outlays for construction equipment
Reduction of waste materials	Low bonding material yield
High accuracy of printed elements	The need to constantly control the quality of the printed object
Free-form making and easy modification	Insufficient conditions for the completion of the building structure as a whole
Shorter the construction completion time	The correct implementation of the additive printing technique strictly depends on the raw materials
Lower investment costs-relatively low technology costs	
More accurate and easier construction logistics	

The disadvantages associated with the implementation of additive technology also include issues related to the loss of many jobs and the need to employ highly qualified workers [30,31].

Three main technologies are used to print entire buildings and larger structures as well as large elements: CC (Contour Crafting), Concrete printing and D-Shape [32,33]. It should be remembered that the use of additive technology in building industry is not only the creation of structures but also the production of other building elements and more. Thanks to this technology, we can create garden accessories, bathtubs, washbasins, bridges and footbridges and many other elements used in everyday life [34,35]. An example of a building elements printed in 3D technology and the process of manufacturing is shown in Figure 1.

(a) (b)

Figure 1. An application of 3D printing in the building industry: (a) building elements printed with 3D technology; (b) manufacturing process. *Source: Own.*

Technological solutions, construction of printers

The most important element of additive manufacturing is an innovative approach to the production process. It is a little bit different for various types of 3D printing processes, but significantly different from the traditional manufacturing process [8,11]. In the case of 3D printing, the first stage is to design a 3D numerical model. This is usually done by using CAD software, but this is not the only possibility. Currently increasingly the model might be designed with 3D scanning, created by the designer or based on another existing design. Later, the numerical model is transformed into the standard tessellation language (STL) format. STL is the most recognizable format for 3D printers. The subsequent step is connected with uploading the file to the computer that controls the 3D printer. Some changes could be implemented in the object at this stage by setting up the device, for example, size. When working, the 3D printer should be checked regularly. Supervision of the process is needed in case of errors. When the process is completed, the printed object is taken from the machine (or in the case of large-scale devices in the construction industry, the 3D printer is removed from the object). The final step is post-processing. This process could involve different technical operations, such as brushing off the object from remaining powder, support removal, painting, polishing or curing [11,36]. The manufacturing process could be different for each construction, because a variety of techniques can be applicable in additive manufacturing. The American Society for Testing and Materials (ASTM) divided 3D printing technologies into seven categories [37]:

- Material Extrusion, together with Fused Filament Fabrication (FFF) and Fused Deposition Modelling (FDM);
- Sheet Lamination;
- Material Jetting;
- Vat Photopolymerization, incorporating Stereolithography (SLA), Continuous Liquid Interface Production (CLIP), and Digital Light Processing (DLP);
- Powder Bed Fusion, together with Selective Laser Sintering (SLS), Multi Jet Fusion (MJF), and Direct Metal Laser Sintering (DMLS);
- Binder Jetting;
- Directed Energy Deposition.

In the construction industry, there are the most popular: material extrusion and powder bed fusion. The most popular seems to be material extrusion. Nowadays, it is the most applied technique for large-scale objects. Extrusion technology is characterized by a layer-by-layer structure. It is an effect the material extrusion through the nozzle mounted on a gantry to print. It also allows the construction to be printed on-site [4,11]. The application of powder bed fusion gained popularity for the smallest elements that required more precision and should have a high aesthetic value [38,39].

Materials used to print buildings

The possibility of quick construction of residential buildings using 3D printing techniques allows for reduced

production costs and creates hope for people who, due to the high prices of traditional houses and low wages, cannot afford to buy their own apartments. This tendency applies to all European countries where housing is becoming too expensive for lower-income groups [27,28]. The use of correct materials is not without significance in 3D printing technology [40]. On the one hand, it should use cheap materials, since the aim is to make it possible to obtain cheaper buildings, and on the other hand, these materials should have specific properties. Materials used for 3D printing should be able to cure quickly, should be able to maintain a spatial structure (not spill), be able to be extruded, etc. Of course, one of such materials is conventional concrete based on Portland cement, but it should be remembered that not all elements of houses or other objects can be printed from concrete, and not everywhere it is possible [40].

In the last few years, many ideas have arisen related to the use of 3D printing technology on the Moon, using the materials that can be found there. These plans assume the use of regolithic dust and sulfur concrete. These materials can be obtained on-site and there is no need to transport them. These are very advanced plans that are already implemented and tested to some extent. The vision of creating objects on the Moon in 3D printing technology is no longer as futuristic as it seemed not that long ago. Printer designs assume the installation of photovoltaic panels on printers so that the entire 3D printing system is powered by solar energy [41,42]. Currently, one of the very interesting materials for additive technology in the building industry are geopolymers. Geopolymers are materials known as inorganic, amorphous, synthetic, and aluminum silicates with specific compositions and properties. Comparison of geopolymers with other building materials is shown in Figure 2 [43].

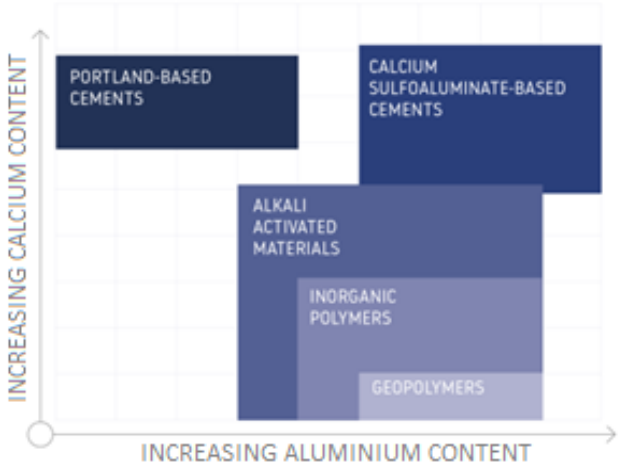


Figure 2. Classification of binders and geopolymers. *Source: [43]*

Investigation on geopolymers is performed primarily to reduce Portland cement application, because of the needs of reduction the influence of the building materials on environment. Related research objective is increasing the usage geopolymers in the construction industry and applicability this material in large scale. The provided analysis show that this material can be much more effective that traditional concrete, including decreased nearly 50% energy demand and almost 32% total costs [44]. Moreover, this material gives a reasonable promise of limitation in CO_2 emissions and reduction in global warming [45,46].

Geopolymers are, most often, hard, and mechanically resistant solids that resemble natural stone or concrete. All types of geopolymers are characterized by very high refractoriness. Most methods of geopolymer synthesis come down to one process: comminated, dried pozzolanic material (metakaolin or fly ash) is blended with an aqueous solution of a suitable silicate (e.g., sodium or potassium silicate) joined with a strong base - usually concentrated sodium or potassium hydroxide. The paste obtained has a similar behaviour to cement: it solidifies to the required elements in a few hours [47,48]. This process was traditionally applied in casting technologies. Today, there are some experiments to apply it to 3D printing process. One of the first trials was conducted in Irkuts (Russia). The successful tests of the use of géocrete (geopolymer concrete) in printing structures were carried out on a mobile 3D printer from Apis Cor [49]. This system was developed by Russian-Italian company RENCA. This company has developed and assessed various material compositions based on a geopolymer binder. Tests have shown the high performance of geopolymers, including a very good consistency suitable for extrusion

technology [49]. Moreover, the company declares the obtained formula is the most relevant for the additive technology, because of proper setting time, high thixotropy and relevant fluidity of the geopolymer paste. It should be noted that the products achieved are characterized by high aesthetic values and excellent mechanical strength (compressive strength - 100 MPa) [49,50]. Additional advantage for construction industry form the application geopolymers in 3D printing technology can be short construction time and environmental benefits, including usage of industrial by-products as a raw materials [14].

However, 3D printing for geopolymer materials is a challenging task and is connected and numerous trials and failures (Figure 3a) make it is a promising alternative for concreate constructions. The investigation also show the possibility to join this two materials in so called hybrid solutions (Figure 3b) [15,51].

(a) (b)

Figure 3. Trials of 3D printing: (a) 100% geopolymer based on fly ash - too high viscosity; (b) Hybrid solution – geopolymer and concreate. *Source: Own.*

For the further development of 3D printing technology, new materials with programmable properties are necessary. It could be achieved with different additives, for example, gypsum waste that helps with regulation the setting time [52]. Currently, construction solutions are available that allow 3D printing for the construction industry with the following materials [43]:

- Various types of concrete and hydraulic binders;
- Geopolymers and alkaline activated materials;
- Plastics, rubber;
- Sands and regolith, clays;
- Salt, waste from coffee, tea, and wine production.

Examples of printed objects around the world

The application of additive manufacturing in the construction industry is connected to the search for opportunities to improve efficiency and profitability in this area. One of the most exploited technologies in recent years in the area of the building industry is Building Information Modeling (BIM). BIM technologies use modern software to improve the efficiency of management in the whole construction project at all stages – starting preconstruction, trough the on-site coordination, up to implementation the changes during the project [53,54]. Nevertheless, BIM changes the management of the construction process, it does not change the process itself. The traditional building methods have been similar for decades. Meanwhile, additive manufacturing introduced changes in construction technology as such. It has the potential to improve the efficiency and profitability of the building process, make this process more sustainable, and achieve a positive environmental impact [8,54]. However, as it exists today, additive technology has many limitations, for example size of the structure, the material used, the requirements for skilled labor, as well as industry reluctance [8,55].

Recently, 3D Concrete Printing (3DCP), realized by extrusion method become very popular as an object of research and development works in the construction industry [55,56]. It is considered an emerging technology that has a potential to revolutionize the construction industry [57,58]. In the construction industry, the use of 3D printing is constantly growing. The new architectural tool, which is the use of this technology, gives unlimited possibilities in the selection of form and technique. Today, 3D printing is used for not only residential houses,

but also many other urban elements. This technology on an architectural scale is becoming more and more popular, offering many benefits [29,56,59]. One of the spectacular architectural structures is the longest 3D printed bridge in the world.

Case study of bridge in Shanghai

The concreate bridge in Shanghai in one of the first of this type constructions made in the world (Figure 4).

Figure 4. 3D printed bridge in Shanghai. *Source: [60].*

It was made using extrusion technology (contour crafting) with the robotic arm for feeding the material. The basis for the contour crafting method is the quick application of successive, thin layers of materials, in this case concrete, one on top of the other according to a computer pattern. In case of residential housed this technology leaving space for windows and doors in the walls [61,62]. In case of the analyzed bridge this technology allows to obtain aesthetic shape coherent with architectural vision made by Professor Xu Weiguo from the Tsinghua University (School of Architecture) - Zoina Land Joint Research Center for Digital Architecture [62,63].

The bridge project was inspired by the ancient Anji Bridge in Zhaoxian, China. The object is composed of 44 hollowed-out 3D printed concrete elements and is the 26.3-meter-long bridge. In addition, the handrails are made from 68 elements. The bridge was created from some components. Each of them has been performed in additive manufacturing technology. As a base material, concreate reinforced with polyethylene fiber was used [64]. The application of composite material allows joining the structural performance of conventional materials with increasing level of material ductility by fiber addition. The bridge was printed by two automatic arms in 450 hours. The streamlined process is estimated to have resulted in savings of 33% production costs compared to the more conventional construction process [65]. The use of the new technology can cause a change in construction projects due to its characteristic of automation and robotic work [63]. It also has the potential to replace labor with machinery on a construction site [63].

Dubai Municipality - case study of an administrative building

The 3DCP technology also finds application in residential and public buildings. One of the most advanced projects in this area took place in Dubai (Figure 5). The two-storage administrative building for Dubai Municipality was design and performed with usage nearly fully automated construction process with significant reducing formwork works and minimalizing human resources [64,65].

The main contractor for this project was the previously mentioned Apis Cor that cooperates with the RENCA company in Irkuts, Russia, in testing new materials, geopolymers for 3D printing. Despite the environmental conditions in Russia, the climate in Dubai is more favorable for the construction industry, including 3D printing technology, due to the more suitable temperatures for this process. The additive manufacturing technology was applied to the manufacturing of wall structures. They were 9.5 m tall and covered an area of 640 m^2 [66]. Today, it is still one of the largest 3D printed structures [66]. The material used for the production of the two-story public building was a gypsum-based mix developed by Apis Cor. It is also worth to noticing that structural calculation and analysis covered all areas required for the building: seismic actions, floor masses, accidental torsion effects,

etc. The prototype solution was tested according to ASTM norms, including mechanical properties (compressive strength and three-point flexural test for material and elements), absorption and durability test. Due to the lack of separate building regulations for building in 3D printing technology, tests corresponding to conventional building materials were applied [67,68].

Figure 5. 3D printed administrative building for Dubai Municipality. *Source: [64].*

Case study of 3D printing applications in the construction industry

The other application additive manufacturing in building industry that was connected with many benefits is production ten small, full-size prefabricated houses by Shanghai-based Winsun in 2013. The main benefit of the usage of this technology was the time for production - ten whole houses were 3D printed in one day. The additional benefit was associated with the price of this project only, $ 4,800 for one house with an area of 200 m^2 [69]. Each house was 6 meters high and more than 12 meters wide [69]. This cost-efficiency was possible mainly thanks to reducing employment and saving production costs [69]. However, it is worth noticing that these houses were not completely printed on-site. They included mainly pre-fabricated elements in the company and next shipped to the construction site. On the site, there were installed on a slab foundation and there reinforced by steel rods [69]. Moreover, some construction elements, such as roofs, doors, and windows, were not made in additive manufacturing technology. The used 3D printing technology was focused mainly on the walls. These elements were made in the technology that remained the hollow bridge that ensures a more lightweight construction and increasing isolation properties. The internal spaces were reinforced by the diagonal zigzag system to obtain the proper strength of the construction elements [69]. At the same time, however, it provides enough space for plumbing and electrical installations. The material used for this project was the composition designed for 3D printing process. It was also registered as a trademark. The composite consists of concrete, cement, gypsum, glass fiber reinforcement, etc. The important property of this mixture is the high early strength of the material and short time of curing - within a few days. Important feature of the designed material is also sustainability – about half ingredients by mass comes from recycled construction waste [69].

The similar material (concrete, gypsum glass fiber etc.) a few years later realized also more ambitious construction, the first 3D printed office building in the world. This building was dedicated to the United Arab Emirates National Committee as the headquarters of the Dubai Future Foundation (DFF) – Figure 6 [70,71].

The whole structure is 250 m^2. Construction technology was similar to previous project: not all elements were produced on site. It is estimated that about half of them were produced at the factory, shipped and assembled on site. This whole process involves only 18 workers (printer operator, assembly workers, mechanics, and electricians' staff). This number was significantly lower than in the case of traditional construction works. Moreover, the new technology allows considerably shortened the construction time – the whole project was finished within only 17 days. Both of these elements help to reduce the investment cost of about $ 140,000 [70,71]. It is worth to noting that estimation shows huge reduction of manufacturing time (50 – 70%), reduction of labor cost (50 – 80%), and minimalization of construction waste (30 – 60%) [71].

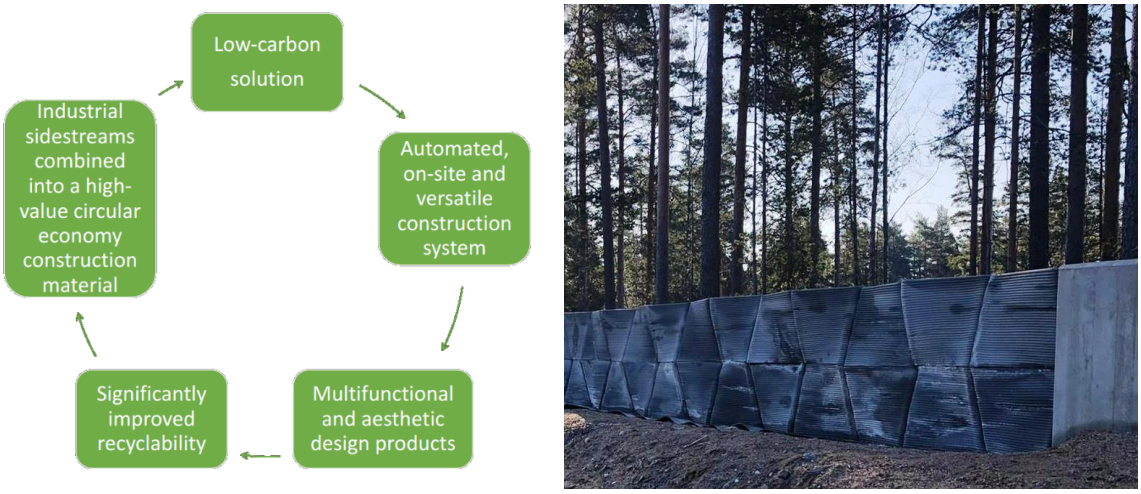
Figure 6. 3D printed office building in Dubai. *Source: [70].*

Case study of small 3D printed urban architecture in Lapperanta

The other example of using 3D printing technology for construction purpose is the project "Urban infra revolution: Circular economy materials and the development of novel methods to produce recyclable and functional urban construction products", co-financed by the European Regional Development Fund through Urban Innovative Actions (UIA) [72,73]. The project was implemented between 2017 and 2020 by the consortium, which involves: municipal - city of Lappeentanta, Finland (lider), four small-medium enterprises (SME), five private enterprises (large), two universities, and Region Development Company. The total cost of the project was: EUR 4 336 568.40 [11,72,73]. This project implemented new solutions to reduce CO_2 emissions in the development of urban construction. It includes three innovative components: material, technology, and product. The first innovation was new materials that were designed to replace concrete in urban architecture. They are based on side streams from local industry, such as ashes, green liquor dregs, mine tailings, construction and demolition waste. The additional material requirements were coherence with additive manufacturing technology (3D printing). The application of this technology for the geopolymers was the second innovative aspect. The challenges were related to the automation of the technology (efficiency, zero waste) and its use in harsh Finnish environment (low temperature). The third novel aspect were new products for urban architecture: elements for a skate park and a noise barrier. The design process for these products was supported by new technologies (3D modeling and augmented reality) and actively involved the Lappeenranta city society [8].

Despite difficulties during the project implementation, the project objectives were achieved. The most important was material in line with the circular economy approach and possibly to application of this material in 3D printing technology. The designed geopolymer composite material includes 99.6 % of circulative materials and is 100 % recyclable and printable (Figure 7a). Furthermore, the composite is based on local sources (not more than 100 km), effectively reducing the cost of transportation and CO_2 emissions related to shipping. The planned additive technology was successfully developed. In the laboratory for testing materials, the robotic arm was used. For scale-up, a new solution, a large format 3D printer, was developed, where prototype elements were performed. Both new products were designed and produced. They were dedicated to urban architecture. They were characterized by aesthetic and safe multifunctional structures through a new kind of shape, they increase attractiveness of the city. One of these products, a noise barrier (100 m in length), is presented in Figure 7b.

Additionally, the business model for a new branch was created that will be based on this project, taking into consideration the closed-loop circular economy. This model estimates that the implementation of the results of this project will generate 50-200 new jobs directly or indirectly to local industrial organizations over the next 5-8 years [72].



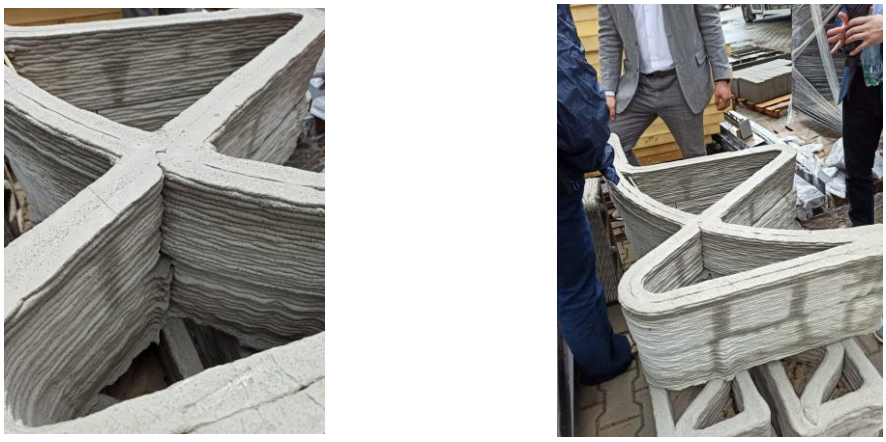
(a) (b)

Figure 7. Urban infra revolution project: (a) Diagram for presenting the idea of circular economy applied in the project. *Source: [73]*, (b) Final result of the project – noise barrier made in 3D printing technology *Source: [72].*

Case study of hybrid materials for 3D printing of residential houses

The interesting solution was implemented in the project entitled "Development of 3D printing technology for construction and facade prefabricated elements made of concrete composites and geopolymers" funded by the Polish National Centre for Research and Development with using found from the European Union. This project was realized between 2019 and 2022 by Polish University and SME company. The main aim of the project is the design and development of the innovative large-format printer using geopolymers for 3D printing for residential houses (ready components for production of residential houses in place). Total value of the project was: ca. 1 784 050.00 EUR co-financing: ca. 806 342.38 EUR. The original conception was printing the building element on heated plate in horizontal way (max. high—50 cm), however this idea had been changed during the project [15,74].

The first laboratory trials in presented project (testing materials) were made on modified 3D printer for concrete – WASP 2040 with pneumatic feeder. For the scale-up technology the large-format printer was used - ATMAT Galaxy 3D printer (ATMAT, Cracow, Poland) [15,74]. During the research related with materials design for the additive technology, some challenges appeared. The most important was connected with paste liquidity. It was solved by optimization liquid and solid ratio and creating the hybrid material, that included geopolymer and concreate components [15,74,75]. The geopolymer ingredient based on fly-ash or metakaolin as a raw material [15,74]. The changes in materials required were strictly related to the additive manufacturing process, including parameters such as print speed, the thickness of the layer, and print nozzle geometry [74,75]. Despite some difficulties the construction elements with complex geometry has been obtained – Figure 8.



(a) (b)

Figure 8. 3D printed elements developed in the framework of the project: (a) the element with visible layers, (b) the element compared to the human scale. *Source: Own.*

Although the laboratory investigation show a slight difference between the compressive strength of materials developed by casting and additive manufacturing technology [8,76]. The semiindustrial trials show that this difference is quite huge – the values for the compressive strength for 3D printed samples are approximately 40% lower than for cast samples [74]. This phenomenon was limited when the geopolymer based on fly as a raw material was used instead of metakaolin (the difference was approximately 20%) [74]. The investigation also confirms dependence on the direction of the mechanical properties in 3D printed samples – the compressive strength in the perpendicular direction was approximately 10% lower than for parallel direction [74].

Opportunities and barriers to the use of additive technologies in construction

The technology of additive manufacturing gives new perspectives and opportunities in the construction industry. It brings a lot of benefits that may be categorized to four main groups, as follows:

- Design complexity, including more interesting architectural shapes, aesthetic architectural products (create irregular and exotic contours) as well as possibility of construction in harsh environments;
- Reduction of labour costs and increasing the productivity, possibility to eliminate the need for large staff to create features such as concrete walls [29,76];
- Time savings and cost reduction, especially by preparing prefabricated structural elements that are assembled on-site; it is estimated that with implementation the production technology can reduce the cost of materials and labour by up to 80% [76,77];
- Sustainability – reduced environmental impact, including waste minimization.

However, the application of 3D printing technology in construction industry has a lot advantages, it has also some limitations. Some of them are connected with the lack of maturity of this technology that is applied only about a decade to full-scale applications. The most important factor related to the current state of this technology is the sheer size of the printers [78,79]. The limited size of the device have influence on the limitation of the size predicted construction [78,79]. Fortunately, the new technical solutions in 3D printing systems partially overcome this limitation and give new perspectives [79].

Another barrier to a wide implementation of additive manufacturing in the construction industry is the appropriate material. However, good knowledge about plastic behavior in the 3D printing process of the printing concrete, its composites and similar materials is still a challenging task [29,79], including problems related to interlayer bonding [80]. Cementitious materials in this aspect are up-to-date and an important research topic. Concreate is not the only one material that cause the most problems with the application. Even more problematic to application in this technology are wood or steel used as the traditional building materials in the construction. Additionally, even modern devices are limited to printing only one type of material at a time [79,81].

The other element that hampers the creation of genuinely 3D printed structures is building standards and regulations, and, in fact, the lack of appropriate legal regulations in the field of 3D printing in construction. Currently valid building codes and procurement standards do not include additive technologies as building technology, especially some elements such as foundations. It makes it challenging to implement 3D printing in a wider scale. Also, this problem affects building elements and components [82–84], including lack of proper standards for material testing. These types of standards and regulations are necessary to implement large-scale construction projects legally.

Impact

The assessment of the potential impact of use of additive manufacturing of concreate materials in the construction industry is a complex problem. Some of the described case studies for prototype construction clearly showing the positive economic and environmental impact of reduction of costs and wastes reduction [71,84]. However, one should be aware that this influence estimated for this investment usually does not takes into consideration the indirect costs such as training proper workers with knowledge about high technologies and development of modern equipment and software necessary for this kind of investment. Additionally, in this estimation, the problems with durability of the materials are omitted. This is because 3D printing is a relatively new technology and this kind of investigation is based only a laboratory research [85,86]. Although the estimation of economic and environmental impact is not a trivial tasks. Even, the more complicated issue is estimation of the implementation of social impact of the 3D printing technology in construction industry. On hand in can influence on the decrease in price on the construction market and the increase in the availability of residential houses, but a wider adaptation of this technology can decrease the value of the entire market.

Cheap and easily available houses can cause a tendency to more often changing a house and create the large amount of unsettled objects in some areas. On the other hand, the cheap technology can be perceived as a worse one and only as a temporary solution. Regardless of the scenario that will occur in the future, it is worth noting that 3D printing has a huge potential to be breakdown technology in the construction industry in some next decades.

Conclusions

Today, only a few prototype applications of additive manufacturing technologies have been developed in the construction industry. However, 3D printed technology has great potential in this area because of its effective application on an industrial scale, although it still requires development and optimization. The article clearly showed the advantages of the broader applications of 3D printing and successful implementation in various areas of the construction industry. It also indicates that this technology requires a lot of work to be fully effective. The main challenges are connected with scaling up the technology from the laboratory to a fully effective method of industrial production.

Conflict of interest

There are no conflicts to declare.

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IMPROVEMENT OF THE TECHNOLOGY OF MARSHMALLOW WITH THE ADDITION OF PLANT RAW MATERIALS

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Abstract
Every year, the interest in functional nutrition is growing in the world. Consumers are increasingly rejecting products containing sugar, artificial preservatives, dyes, flavorings, flavor enhancers, etc. There is a growing public interest in healthy food products and the ingredients used in these products. Despite the increase in the price of such products, marketing research confirms the demand for them and the willingness of the population to "overpay for naturalness". The article is devoted to the development of the formulation and technology of a pastila-type product with a functional purpose using non-traditional raw materials (coconut sugar, fructose and blueberry powder) instead of sugar. The organoleptic and physicochemical indicators of the quality of new products were determined. The pastila-type products are enriched with protein, dietary fibers, minerals (potassium, calcium, magnesium, zinc) and vitamins (C, PP, groups B, A).

Keywords
marshmallow; additives of plant original; glycemic index; antioxidant capacity; quality indicators of marshmallow; chemical composition.

Introduction

Consumption of low-quality food products (low-quality means a combination of high energy and low nutritional value, as well as a deficiency of dietary fibers and micronutrients) reduces the quality of life and leads to the occurrence of a number of serious diseases. Sugar confectionery products, due to their taste properties, are in high demand among various groups of the population. They are characterized by high caloric content, easy digestibility, are effective suppliers of energy in the human diet, have an attractive appearance, pleasant taste and serve as a supplement to the human diet. But this group of products, as a rule, has a high sugar content and a significant glycemic index, which causes a sharp increase in the level of glucose in the blood [1]. The following is the priority direction for expanding the assortment of whipped confectionery products the use of new raw components that make it possible to change or adjust the functional and technological properties of whipped masses, as well as texture, quality indicators, and extend the shelf life of marshmallow products. In works [2–4], the expediency of using viburnum juice, blackcurrant pomace, pumpkin puree, redcurrant jam, and chicory powder in the technology of enriched pastille products is substantiated. In work [5] it is proposed to use aqueous solutions of anthocyanin pigment of honeysuckle and black currant in the production of marshmallows. The use of red beet juice and puree and physalis juice as natural dyes in the zephyr technology

allows you to enrich it with general phenols and flavonoids and thereby increase the antioxidant properties of the product. It also allows to get a natural product with the same color and aroma that artificial colors and flavors give [6]. Scientists of KhSUFTT developed a fruit and vegetable semi-finished product (apple - 60%, pumpkin - 20%, beetroot - 20%) with a dry matter content of 45% and confirmed the feasibility of using this semi-finished product in the composition of marshmallows by replacing 75% of apple puree [7]. The authors established that the use of plant powder extracts in marshmallow technology (powders obtained using low-temperature technologies) allows to enrich the product with biologically active substances. In addition, the quality indicators of the new product are improved [8]. To expand the range of functional confectionery products and prevent iron deficiency anemia, spinach and tomato extracts (25:75) are added to the marshmallow recipe. This product contains 1.159 mg/100 g of iron and 44 mg/100 g of vitamin C [9]. Semi-finished products from Jerusalem artichoke roots (pure, paste, powder) and concentrated fruit juices (apple and pineapple) are used as enrichment additives in marshmallow technology. This allows to increase the content of vitamin C in marshmallows by 2 - 4 times, potassium by 4 times, magnesium by 7 times, antioxidant activity by 3 - 5 times, compared to the control; enrich with inulin; reduce the energy value [10]. The use of lingonberry enzyme hydrolysate in the production of marshmallows made it possible to obtain a product enriched with physiologically functional ingredients. Also, this marshmallow is characterized by good organoleptic properties due to the appearance of natural dyes - anthocyanins [11]. The authors [12] proposed the use of barberry fruit extract as a natural dye in confectionery technology, including marshmallows. It has been established that barberry extract has greater color stability compared to beet juice concentrate; products with added extract have better antioxidant properties.

A new marshmallow technology based on blackcurrant puree and the addition of basil powder was developed [13]. The composition of marshmallows with Jerusalem artichoke syrup, milk whey, a mixture of apple and blueberry puree is known, which allows to obtain products with reduced sugar content and increased nutritional value [14,15]. A marshmallow technology was developed with a partial replacement of apple puree with a mixture of blueberry and strawberry puree. The product obtained by this technology is characterized by an increased content of dietary fibers, macro- and micronutrients, anthocyanins [16]. The use of new-generation sugar substitutes in marshmallow technology (referring to polyols with prebiotic properties and a low glycemic index) makes it possible to obtain products with reduced sugar content and increased nutritional value [17]. Numerous works are devoted to the use of fructose in the technology of pastila-type products to improve the quality of products, increase the shelf life, reduce the sugar content, obtain products with a functional purpose, and expand the raw material base [18–23]. Scientists [24] improved the formulation of whipped confectionery products by replacing sugar with erythritol and a small amount of sucralose and introducing an active ingredient (a multivitamin mixture or vitamin C or a mixture of B-complex vitamins) into the products. Such products have low energy value and glycemic index, unique structure, extended shelf life and increased nutritional value. The authors [25] studied the influence of sorbitol and sweet potato inulin extract on the physical, chemical and organoleptic characteristics of marshmallows. It was established that the product with the addition of 2% sweet potato inulin extract and 50% sorbitol has the best characteristics.

Numerous studies of sugars, sugar substitutes and sweeteners were carried out at the NUFT under the leadership of Dorohovich. The physico-chemical and physiological properties and the possibility of use in the production of dietary functional confectionery products with reduced glycemic and caloric content were determined [26–29]. Coconut sugar is a sweet product obtained from the juice of the coconut palm and is widely used as an alternative to other types of sugar. This sugar has a subtle, less sweet taste than regular sugar with a caramel aftertaste. Coconut sugar has a low glycemic index of 35 and is rich in nutrients [30]. Cryopowders are environmentally friendly products made from certified plant raw materials without the use of chemical stabilizers. Their feature is a high content of biologically active substances, which during cryomechanical processing preserve up to 95% of the original composition of useful substances. The introduction of cryopowders makes it possible to increase the nutritional value of finished products, to exclude synthetic dyes and flavors from the recipe, to obtain a variety of colors, as well as to improve the structural-mechanical and physico-chemical indicators of finished products [31]. Blueberries contain a large amount of anthocyanins, up to 12% of pyrocatechin group tannins, organic acids (citric, malic, succinic, etc.), vitamins C, PP, B1, B2, carotenoids, minerals: potassium, calcium, magnesium, and iron. Blueberry myrtilin has the property of lowering blood sugar. Pterostilbene provides it with a pronounced cholesterol-lowering effect. Flavonoids are able to successfully fight inflammatory processes and protect the mucous membrane of the stomach, increasing the secretion of mucus. The optimal ratio of vitamins of groups B and C gives blueberries a vaso-strengthening and anti-anemic effect, improves memory and resistance to stress [32]. After analyzing the presented scientific improvements, it was

concluded that the creation of new technologies of functional marshmallow is relevant. Marshmallow has a high glycemic index due to the significant content of white sugar and causes a sharp jump in the level of glucose in the blood. And therefore, they cannot be consumed by all sections of the population. In addition, it is poor in vitamins and minerals. This can be corrected by replacing white sugar with alternative types of sugars that have a lower glycemic index and by introducing berry powders obtained by low-temperature technologies, which have better indicators of the content of vitamins, macro- and microelements. In order to solve this problem, we suggested replacing white sugar in the marshmallow (zephyr) formulation with a mixture of coconut sugar and fructose and adding freeze-dried blueberry powder.

Methods of research

Materials

Coconut sugar (manufacturer, VanaVita, Germany), blueberry powder (SOK "Unikrasa", Ukraine), fructose (OOO "Barvysta", Ukraine), agar (ROKO, Spain), apple puree ("Agrana Fruit" Ukraine), molasses starch (PJSC "Dniprovsky starch-molasses plant"), citric acid ("Kharkiv plant of food acids", Ukraine).

Method for determining the content of anthocyanins

It was determined by measuring the optical density of the investigated solution at a wavelength of 490 nm (layer thickness 10^{-2} m). The sample was prepared by diluting 1 cm^3 of the test solution with a buffer solution with pH=1.0 to 10 cm^3. A buffer solution with pH=1.0 was prepared by mixing 0.2 N potassium chloride solution with 0.2 N with a solution of hydrochloric acid in a ratio of 25:67. The amount of anthocyanins was calculated using the formula:

(1) $$C_A = \frac{A_{490}^{pH=1,0}}{49}$$

where:

C_A - is the concentration of anthocyanins in the solution, mg/100 cm^3

$A_{490}^{pH=1,0}$ - light absorption at λ=490 nm of the sample of the investigated solution (pH=1.0; layer thickness 10^{-2} m)

49 - is the coefficient calculated from the angle of inclination of the calibration graph [33].

The content of pectin substances was determined according to the universal method [33]. The essence of the method is to determine the content of pure pectin in the form of a uronide component. (0,2…0,5)×10^{-3} kg of powder was moistened with a few drops of ethyl alcohol, 10 - 20 cm^3 of water was added and mixed. Then 1 - 2 cm^3 of 1 N NaOH was added to the resulting mixture and left for saponification for 20x60 seconds. After that, pectinic acid was precipitated with 2 - 3 cm^3 of 1 N HCl, and 50 cm^3 of 0.1 N HCl was immediately added. The total mass of the solution (G) was fixed by adding individual components. The sediment was filtered through a paper filter. 10 - 20 cm^3 of filtrate was taken and titrated with 0.1 N NaOH. The remaining filtrate, the filter cake and the filter were combined and titrated with 0.1 N NaOH. The pectin content was calculated according to the formula:

(2) $$C = \frac{V \cdot 176 \cdot 0,1}{1000}$$

where:

V - is the volume of sodium hydroxide used for the titration of pectic acid, cm^3

176 - molar mass of pectic acid equivalent, g/mol

0,1 - 0.1 is the molar concentration of the sodium hydroxide solution equivalent, mol/l.

Method for determining the content of ascorbic acid

A blue solution of 2,6-dichlorophenolindophenol is reduced in the presence of chloroform to a colorless compound with colored plant extracts containing ascorbic acid (Tilmans reaction) [34].

Method of tannins determination

The method for determining tannins is based on their easy oxidation by potassium tetraoxomanganate in an acidic medium in the presence of indigosulfonic acid [35].

Method of determining the antioxidant capacity (AOC)

The antioxidant capacity of raw materials and finished products was determined by the method of galvanostatic coulometry. To prepare the extracts, a weight of the appropriate crushed sample with a mass of (5.0…6.0)x10^{-3} kg was ground with 10 - 20 cm^3 of the extractant (distilled water) and quantitatively transferred to a 100 cm^3 flask, the volume of the solution was brought to approximately 100 cm^3 and weighed. The contents of the flask were kept for 10x60 s, mixed and filtered. (0.2…5.0)x10^{-3} of the obtained extracts were placed in the coulometric cell and titrated with electrogenerated bromine at currents of 1 - 5 mA depending on the concentration of the solution under study so that the titration time was 300 - 500 s. Bromine was generated from an aqueous solution of 0.2 M potassium bromide in 0.1 M sulfuric acid. Fixation of the equivalence point was carried out by the potentiometric method. AOC (Cl/ 100 g) of herbal supplements and products was calculated according to the formula:

(3) $$\mathrm{AOC} = \frac{100 \cdot I \cdot t \cdot m_{\mathrm{e}}}{m_a \cdot m}$$

where:
I - current strength, A
t - time to reach the end point of titration, s
m - mass of the sample that was taken for analysis, g
m_{e} - mass of the extract, g
m_{a} - mass of the aliquot used for analysis, g.

Methods of assessing the quality of semi-finished products for the production of marshmallows

The foaming ability of the marshmallow mass (%) was determined by measuring the volume of the recipe mixture before and after whipping, then the amount of foaming ability (FA, %) was calculated according to the formula:

(4) $$FA = \frac{V_2}{V_1} \cdot 100$$

Where:
V_1 - is the volume of the recipe mixture to be whipped, cm^3
V_2 - is the volume of the recipe mixture after mixing, cm^3.

The stability of the foam after whipping was determined within an hour by measuring the foam volume every 15 min and dividing it by the initial volume. The nutritional value was determined by the calculation method [36]. Determination of the content of anthocyanins, pectin substances, low molecular weight phenolic compounds, tannins in finished products was carried out according to the methods given in [33–35].

Statistical analysis

Experimental data were processed with the use of MS Office Excel spreadsheets. Each test or measurement was performed three times. The statistical significance of the obtained results was determined at p <0.05.

Results and discussion

The results of the determination of the quality indicators of coconut sugar are shown in Table 1.

Table 1. Coconut sugar quality indicators. *Source: Authors.*

Indicator	**Characteristic**
Appearance	Brown, free-flowing, uneven in size, there are lumps that fall apart when lightly pressed
Taste and smell	Sweet with a caramel flavor
Purity of the solution	Light brown, clear solution with a slight precipitate in the form of insoluble black inclusions
Humidity,%	0.11

Table 1 shows that coconut sugar is a free-flowing brown product with uneven crystal size, sweet taste and caramel flavor; it gives a clear solution, has a moisture content of 99%. The results obtained will be considered in the development of technology. The results of determining the quality indicators of blueberry powder are shown in tables 2 and 3.

Table 2. Quality indicators of blueberry powder. *Source: Authors.*

Indicator	**Characteristic or value**
Organoleptic indicators	
Appearance	Homogeneous, finely dispersed, free-flowing mass interspersed with berries seeds
Color	Dark pink with a purple tint
Taste	Sweet and sour, typical for blueberries
Smell	Typical for blueberries
Physico-chemical indicators	
Humidity, %	0.5
pH	3.2

It can be seen from Table 2 that blueberry powder is a finely dispersed free-flowing mass, dark pink in color, with a sweet-sour taste, moisture content of 95.0%, pH 3.2. The obtained results will be considered in the development of the technology.

Table 3. The content of biologically active substances in blueberry powder and its antioxidant capacity. *Source: Authors.*

Indicator	**Value**
Anthocyanins, %	2.8±0.2
Pectin substances, g/100 g	9.0±0.5
Low molecular weight phenolic compounds (by routine), g/100 g	11.2±0.1
Tannins (by tannin), g/100 g	5.3±0.3
Vitamin C, mg/100 g	15.0±0.7
Antioxidant capacity, mg AAE/100 g	1092.0±177.6

Studies of the chemical composition of blueberry powder have shown that they contain a significant percentage of biologically active substances (BAS) and have a high antioxidant potential (Table 3). The use of this additive will make it possible to obtain products with increased nutritional value and antioxidant properties. Based on the fact that the structure of marshmallow is a foam - an unstable system, the quality of which depends on the recipe components and their quantity, the influence of coconut sugar, fructose and blueberry powder in the amount of 3, 5 and 7% on the process of foaming in the marshmallow mass was investigated and its stability. During the experiment, 7 samples were prepared: 1 - control sample on white sugar, 2 - sample based on coconut sugar, 3 - sample based on fructose, 4 - sample based on a mixture of coconut sugar and fructose, 5 - sample based on a mixture of coconut sugar and fructose with the addition of 3% blueberry powder, 6 - a sample based on a mixture of coconut sugar and fructose with the addition of 5% blueberry powder, 7 - a sample based on a mixture of coconut sugar and fructose with the addition of 7% blueberry powder. The results of the experiment are presented in Figure 1.

From the obtained results, it can be seen that sample 2 has the highest amount of FC, 53% higher than that of the control sample, which we believe is due to the proteins present in the coconut sugar. Sample 3 also has a fairly high FC value; this is due to the fact that fructose is more soluble compared to sucrose. However, with the introduction of blueberry powder into the marshmallow mass, there is a tendency to decrease FC, and increasing the amount of powder to 7% reduces FC by 114%, compared to the control, which may be related

to the dispersion of the powder and the presence of seeds. The powder adsorbs egg white on its surface, the amount of foaming agent in the total volume decreases, which leads to an increase in surface tension and a decrease in foam dispersion. When determining the stability of the foam in the semi-finished products for the production of marshmallows, it was noted that 15, 30, 45 and 60 minutes after the end of whipping, the foam resistance in all test samples did not change. It is known that for whipped masses of marshmallows on agar, the amount of foaming capacity should be at least 200%. The obtained results indicate that a concentration of blueberry powder of 3–5% is more acceptable for maintaining quality and obtaining the desired effect.
Replacing white sugar with a mixture of coconut sugar and fructose and adding blueberry powder has a significant impact on the organoleptic and physicochemical quality indicators of the finished product. The results of the relevant studies are shown in Tables 4 and 5.

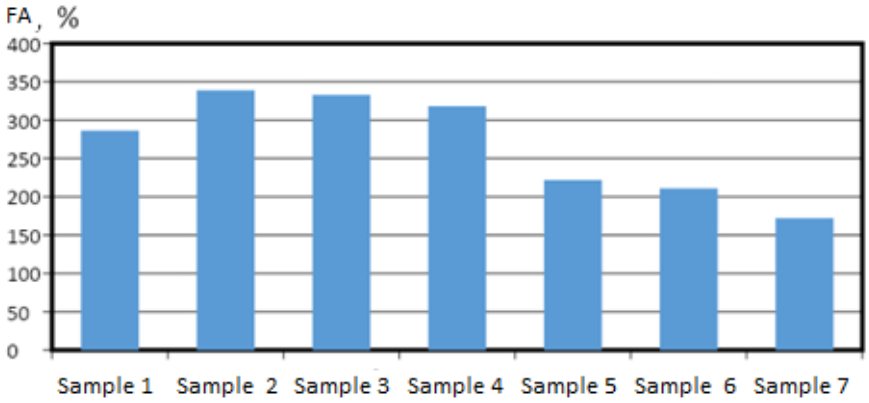

Figure 1. The influence of recipe components on the process of foaming in semi-finished products for the production of marshmallows. *Source: Authors.*

Table 4. Organoleptic quality indicators of marshmallows based on coconut sugar and fructose with different dosages of blueberry powder. *Source: Authors.*

Indicator	**Characteristics of marshmallows**			
	Control sample	Sample based on coconut sugar and fructose with the addition of blueberry powder, % of the total mass		
		3.0	5.0	7.0
Appearance	Round form, corrugated surface with clear outline	Round form, corrugated surface with clear outline	Round form, corrugated surface with clear outline	Round form, corrugated surface
Color	White	Light pink	Pink with red shade	Dark pink with plum shade
Consistence	Elastic, easily broken	Elastic, soft, easily broken		
Texture	Uniform, fine-pored	Uniform, fine-pored		
Taste and smell	Sweet with sour flavor	Sweet with caramel flavor	Sweet with sour and Caramel flavor	Sweet with bright pronounced flavor blueberries

According to the data in Table 4, it can be seen that the research samples of marshmallows have original organoleptic indicators: appearance, color, taste and smell, in contrast to the control sample.

From the table 5. it can be seen that the humidity of marshmallow based on coconut sugar and fructose with the addition of blueberry powder is within the normal range. The acidity of marshmallow increases to 9.0 degrees with an increase in the powder concentration to 7%, which is due to the fact that it contains a significant amount of organic acids. The content of reducing substances in the developed marshmallow samples is increased compared to the control due to the addition of fructose, which is a reducing carbohydrate, and the use of raw materials that also contain reducing substances (coconut sugar and blueberry powder). Based on the research

conducted, we believe that a powder content of 5% of the total weight of the product is rational for achieving the set goals. It was established that the introduction of coconut sugar and blueberry powder into the marshmallow recipe made it possible to obtain products with a sweet taste with sour caramel notes, a more delicate color (pink with a red tint) compared to marshmallows with the addition of blueberry puree [14], which has a delicate, pleasant taste with blueberry flavor and dark purple color. The appearance, consistency and structure of the products remained unchanged. The physical and chemical indicators of the products do not differ significantly [14–16] and meet the requirements of regulatory documents.

It has been proven that the quality of the new products meets the requirements of the regulatory documentation for this type of product, and due to the content of biologically active substances, they are significantly superior to the analog product that does not contain such substances (Table 6).

Table 5. Physico-chemical indicators of the quality of marshmallows based on coconut sugar and fructose with different contents of blueberry powder. *Source: Authors.*

Impact	**According to SSTR (state standard technical requirements)**	**Control sample**	**Marshmallow based on coconut sugar and fructose with the addition of blueberry powder, % of the total mass**		
			3.0	5.0	7.0
Mass fraction of moisture, %, no more	24.0	16.4	18.0	19.6	20.3
Acidity, degree, no less	5.0	5.0	7.8	8.2	9.0
Mass fraction reducing substances,%	7.0…14.0	9.75	14.0	13.6	11.9

Table 6. Chemical composition and antioxidant capacity of the developed marshmallow. *Source: Authors.*

Indicator	**Marshmallow control sample**	**Marshmallow "Blueberry Glow"**
Proteins, g	1.14	1.96
Fats, g	0.1	0.3
Carbohydrates, g	89.75	81.05
Dietary fiber, g	0.43	1.33
Anthocyanins, mg/100 g	-	15.0±0.8
Pectin substances, mg/100 g	7.9±1.2	49.5±1.5
Low molecular weight phenolic compounds, mg/100 g	-	33.0±1.0
Tannins, mg/100 g	-	28.8±0.9
Antioxidant capacity, mg AAE/100 g	14.4±2.9	33.6±1.5

According to literature data [14,15] the use of a mixture of apple and blueberry puree in the marshmallow technology led to an increase in dietary fiber (by 5.0-5.6 times), vitamins B1, B2, B6, B9 and C (in 2- 3 times), as well as potassium (1.2 times), calcium (1.04 times) compared to the control. In addition, the products are characterized by a decrease in energy value by 25%, which is associated with a halving of the amount of added sugar. The authors of the paper [16] established that marshmallows based on apple-blueberry-strawberry puree contain 3.6 times more dietary fiber, 1.1 times more sodium, 2.6 times more potassium, 1.4 times more calcium, 1.8 times - magnesium, 3 times - iron. There was also a 5.5 - fold increase in the content of vitamin C and anthocyanins compared to the control sample.

In the proposed product (Table 6), the content of dietary fibers increases by 3.1 times, pectin substances by 6.3 times. The products are enriched with anthocyanins, low molecular weight phenolic compounds, tannins; the antioxidant capacity increases by 2 times. The products are characterized by a decrease in energy value and glycemic index, which is associated with the replacement of white sugar in the recipe with coconut sugar and fructose (Table 7.)

Table 7. Comparative analysis of calculated values of energy value and glycemic index. *Source: Authors.*

Samples of marshmallows	**Energy value**		**Glycemic index**	
	kcal	% decrease	%	% decrease
Marshmallow "Blueberry Glow"	336.60	7.70	36.00	36.84
Marshmallow on isomalt and fructose [28]	343.75	9.73	23.09	58.99
Marshmallow on maltitol and fructose [29]	343.17	9.90	50.07	11.07

The results of the analysis shown in Table 7 indicate the competitiveness of the innovative product among similar products in terms of caloric content and glycemic activity. The use of coconut sugar and fructose allows labeling the product with "reduced calories" and "reduced glycemic index". The proposed product can be used by people who lead an active healthy lifestyle and people with diabetes.

Impact

The implementation of the obtained results will allow to improve the marshmallow technology using coconut sugar, fructose and blueberry powder and to obtain a product with high consumer properties. This will contribute to solving the important social task of improving the health of the population. Due to the sugar content, confectionery products have a high energy value and glycemic index and are not recommended for consumption by people with diabetes. The research described in this article offers a solution to this problem by completely replacing white sugar in the marshmallow recipe with coconut sugar and fructose, which have lower glycemic indices. In addition, in order to increase the nutritional value, the addition of finely dispersed blueberry powder, obtained by low-temperature technology, is proposed. Research data show the effectiveness of introducing new ingredients to lower the glycemic index of marshmallows and increase their nutritional value. The use of coconut sugar, fructose and blueberry powder in marshmallow technology does not have a negative impact on the environment. The introduction into production of marshmallows based on coconut sugar, fructose with the addition of blueberry powder will contribute to the expansion of the assortment, saturation of the world market with high-quality confectionery products with a reduced glycemic index. The innovative product can be used by people with diabetes and people who lead an active, healthy lifestyle. The new product will be more expensive compared to the product based on white sugar. However, considering the reduced glycemic index of the products (36) and the presence in the composition of low molecular weight phenolic compounds, tannins, anthocyanins, an increased amount of pectin substances, this product will have a sustainable competitive advantage among products of the same category.

Conclusions

It was established that replacing white sugar in marshmallow technology with coconut sugar and fructose lowers the glycemic index of products by almost two times. It has been proven that thanks to new ingredients (coconut sugar, fructose, finely dispersed blueberry powder, obtained by low-temperature technology), the organoleptic properties of the product are improved, namely, the marshmallow acquires a pink color with a red tint and a sweet taste with sour, caramel notes. At the same time, dyes and flavorings are completely excluded from the recipe. According to physical and chemical parameters, the new product meets the requirements of regulatory documentation.

Marshmallow based on coconut sugar and fructose with the addition of 5% of blueberry powder from the total mass has an increased protein content (by 72%), dietary fiber (by 209%), reduced calorie content (by 7.7%). Thanks to the introduction of blueberry powder into the product recipe, the nutritional value of marshmallows is significantly increased, namely, the composition includes low molecular weight phenolic compounds, tannins, and anthocyanins. A significant advantage of the product is its antioxidant properties, which is confirmed by an increase in the antioxidant capacity of the products by almost 2 times compared to the control. Further research will be aimed at determining the effect of coconut sugar, fructose and blueberry powder on the organoleptic, physicochemical and microbiological properties of marshmallows during storage.

Conflict of interest

There are no conflicts to declare.

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THE OFFICE POLITICS ERROR AS A NEW DIMENSION IN PERFORMANCE APPRAISAL IMPLEMENTATIONS: A CASE STUDY AND CONCEPTUAL MODEL IN MALAYSIAN FINANCIAL SECTOR

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Highlight
Causes of organisations performances errors, difficulties and recommendations for financial sector in Malaysia assessed using conceptual research, exploratory factor analysis and practical implication model via SPSS.26.S.

Abstract
Performance appraisal in human resource management is a function that evaluates employees' knowledge, skills, and abilities in executing their job. To assess this appraisal, the employees' key performance index (KPI) can be used. Recently, office politics has been indicated as an activity that may ruin employee-employer relationships and turn the office ecosystem unharmonious. The influence of organizational politics must be avoided during the performance appraisal process. This work depicted practical knowledge and theoretical gaps of the previous studies. Among them are leniency, straightness and stereotype behavior errors. This research was conducted to assess dimensions of organizational politics as one more error in the employee's performance appraisal. The presented study considered a questionnaire directed to 274 officers and clerical staffs who were selected randomly through proportionate stratified sampling method in one of the Malaysian government financial sectors located in Kuala Lumpur, Malaysia. In total 271 questionnaires were returned and used in this study. This work employed Questionnaire of Political Considerations in Performance Appraisal by using robust statistical techniques for testing and validating the results. This study has successfully extracted three reliable dimensions of politics in performance appraisal, namely acquiring benefit, human relations, and control. In addition, this work developed a new conceptual model together with a dynamic and practical recommendation for top management in this field used to avoid the extant error factors.

Keywords
conceptual research; exploratory factor analysis; industrial relations; office politics; performance appraisal errors.

Introduction

Performance appraisal involves two-way communication between a supervisor and an employee with the objective to help employees to improve performance and to help an organization to succeed in a competitive environment. In performance appraisal several biases may occur that affect the result of performance assessment. These biases include unclear standards, halo effect, central tendency, strictness and leniency as well as stereotype [1]. Nowadays, employees' discrimination and superiors' abuse of power always become the issues in an office [2]. Employees always complain that their rights are always being jeopardized or they have been back stabbed by their peers or superiors. Similarly, in performance appraisal, employees complain about the superior always ignoring their contribution to the department because they are not becoming part of the superior's buddy. Hence, discrimination and abuse of power, which are the dimensions of office politics, exist in

performance appraisal exercise. As a result of those practices the organization's performances output are drastically affected.

Currently, political games have become contagious in performance appraisal process. The subordinate only does the task to demonstrate to her/his leader that she/he can complete the given task without looking to the quality of the result [3]. In addition, the subordinate tries to become the leader's buddy so that the leader is leniently appraised by her/his performance. These manipulations can be frustrating to a subordinate who cannot place himself as the leader's buddy or a subordinate who takes a longer time to complete her/his task in order to confirm the quality of the finished task. A good performer, who does not become the leader's buddy, and always emphasizes quality works becomes an unsung hero in the department. This creates a basis for conflict in employee-employer relationship as reported in the literature [4]. In Malaysia, an office politics is always being seen as a negative deed [5]. For a significant part of the Malaysian employees, office politics may create tension in employment relations because office politics involves back-stabbing and power's abuse. When a leader focuses more of her/his time in performing an office politics to achieve her/his own agenda without any considerations for her/his subordinate, it brings a negative impact to the organization as it consumes time and resources [6]. A leader who plays a political game distorts, misdirects, or suppresses the information in order to manipulate situations, so she/he can gain her/his short-term goals. In addition, the leader abuses her/his power to dominantly give a moderate result to a good performer hence this leads to discrimination in the organizations. Thus, transparency is important to construct trust amongst employees especially when considering the performance appraisal process. Transparency is also vital to eliminate uncertainty of information in organizational communication channels. Other studies showed that organizational politics drives job ambiguity and creates a negative trust climate amongst employees [7,8]. In the performance appraisal process, all information regarding an employee's performance must be told to the respective employee, so that the employee becomes satisfied with the performance appraisal result and abolish any ambiguity. Dissatisfaction and ambiguity on performance appraisal amongst employees results in conflict and dispute [4].

Many Industrial Court cases in Malaysia have highlighted the problems occurring in managing employees' performance particularly involving office politics. In Zuraini Abdul Ghani vs Kesas Sdn. Bhd. (Award 733 of 2010), the petitioner claimed that her performance was appraised on the basis of stereotyping bias. The petitioner was questioned about her dismissal due to a letter made by her husband who has also been working in the same company. Her husband has written a letter to the CEO of the company mentioning discrepancies that happened in the company including changing the employee's performance appraisal result. The petitioner has claimed that she was not involved in the incident concerning her husband's activity and felt that her dismissal was made on the grounds of political game. She has claimed that her husband's attempt in highlighting management discrepancies has nothing to do with her and she has been victimized by the management decision. Another example shows that office politics involves employees' discrimination and leader's abuse of power. In Goh Kim Leng vs Dolomite Industries Company Sdn. Bhd. (Award 481 of 2010), the petitioner urged that his dismissal was made on the grounds of office politics, particularly on discrimination. He claimed that upon his dismissal, no appropriate performance appraisal had been made as he did not receive any warning and he had not been given a chance to improve his performance. On the basis of the above presented court cases, it can be said that office politics occurs frequently in Malaysian companies especially when related to the performance appraisal activity. Although Malaysian employees always argue that they have been discriminated by their leader in a form of office politics particularly in performance appraisal, but no study has been performed in Malaysia to indicate the form of politics in performance appraisal execution. Fair and justice as well as transparency have become the rule of thumb in managing employees' performance appraisal [9]. However, negative office politics drive employees' discrimination and leaders' manipulation of power particularly in performance appraisal. When abuse of power exists, discrimination definitely crops up. Dhar indicated that the importance of organizational politics lies in its potential consequences and affects work outcome negatively [10]. They forecasted also that organizational politics provides a negative example to workers' productivity and performance either at individual or organizational levels. Hence, this study aims to give an insight on the type of political games in performance appraisal process and give ideas to top management of a company to control this new type of bias in order to maintain fair and justice in the performance of appraisal process.

Various previous studies, showed that the concept of office politics generates job dissatisfaction between employees [11]. Consequently, office politics might negatively affect employees' job performance, yet these claims and findings need to be validated and tested [12]. Many studies have indicated the consequences of KPI biased practices on the organization performance. The extant studies for Malaysian GLC's indicated the effect of

stereotype practices, recency, and hallo influences the organization's KPI. However, the office politics definitions, dimensions and effects are still vague and require more in-deep analysis on the definitions and interpretation for this kind of biased practices [13–15]. The researchers highlighted mixed results for the recent literature and inconsistency significance of previous findings. For those reasons, the researchers redefined this dimension of office politics in Malaysian's financial sector. Hence, this work presents an evident case study by developing a conceptual model about the criteria and definitions of office politics.

Performance Appraisal

Performance appraisal is a process in performance management function. Longenecker defined that performance appraisal influences one's career and corporate capacity [16]. In performance appraisal, the employee is appraised by her/his knowledge, skill, and ability in performing the assigned tasks. The performance appraisal also evaluates the employee's commitment and communication skill. Performance appraisal makes a significant contribution to the development of a working culture including ethical, equitable and performance oriented**.** Moreover, the performance appraisal process must be appropriate and suitable, and the superior has to demonstrate an effort to reduce potential biases that always happen in appraising workers' performance. Even though, there is a freedom and flexibility in the manner, in which leaders can implement and manage performance appraisal [17]. In the same context Kluger developed Feedback Intervention Theory (FIT) [18]. FIT is a psychological model that focuses on providing feedback to individuals in order to improve their performance. The theory posits that feedback can be used to help people identify areas in which they need to improve and can also be used to reinforce positive behaviors. In this sense, the provided feedback should be specific, focused, and timely. This also means that feedback should be tailored to the individual and should address specific aspects of their performance. However, there is a requirement that performance appraisal must be consistent, ensure equity and maintain fairness. Contrary to what some supervisors believe, the annual performance appraisal is not an end in and of itself. It is a means to achieve an end. Hence, the influence of office politics must be avoided during performance appraisal process [19].

Flaws in Performance Appraisal Implementations

Personal bias is the biggest challenge in carrying out the performance appraisals within any organization. The feedback that results from the performance is meant to guide the modification and adjustment of norms that shape the behavior of workers in the desired direction concerning activities such as mentoring programs, positive reinforcement, counseling, and rewarding of the best-performing employees. Both supervisors and employees influence the performance appraisal by substituting the organizational standards within the evaluation procedures. Supervisors mostly tend to fall prey of subjectivity rather than the objectivity of the employee in attaining organizational goals. Subjectivity leads to unfairness in the formulation of the evaluation decisions [20].

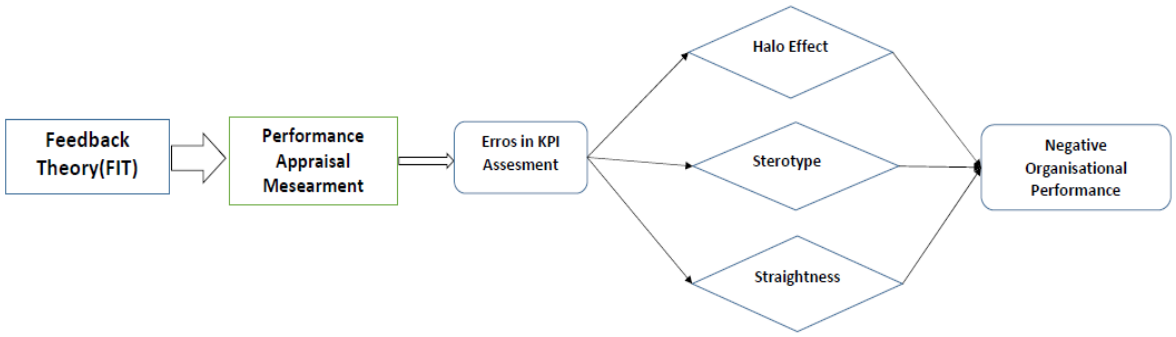

Figure 1. Theoretical framework for flaws in performances appraisal implementation. *Source: [18,21,22].*

As given in Figure 1, despite of recognition that a completely error-free performance appraisal can only be an idealized model, with all actual appraisals being something less than this optimum, we can isolate a number of factors that significantly impede objective evaluation.

The major problems in performance appraisal are:

- Leniency and Strictness error (Errors of leniency are caused by the tendency of the lenient rater to it most of the ratees on the higher side of the scale, while the tough rater places them on the lower side

of the scale);

- Halo Effect Error (Tendency to allow the assessment on one trait to influence assessment on others);
- The Error of Central Tendency (Tendency of not using extreme scores on the judgement scale; most of the rates are clustered in the middle);
- Personal Prejudice (The rater's personal prejudice can influence the objectivity of performance appraisals. If the rater dislikes an employee, he may rate him very poorly);
- Consequence of Appraisal (If the evaluator knows that a poor appraisal could significantly hurt the employee's future, particularly opportunities for promotion or a salary increase, the evaluator may be reluctant to give a realistic appraisal);
- The Recent Behavior Error (The raters generally remember the recent actions of the employee at the time of rating. If a favorable action has taken place recently, the employee will be given a high rating. Otherwise, she/he gives a poor rating when an unfavorable action has been taken recently);
- Similarity Error (When evaluators rate other people in the same way that the evaluators perceive themselves, they are making a similarity error) [21–25].

Office Politics

Office or organizational politics is an activity to show the dominance in authority of a party. Political games in an office are performed either by managers or by subordinates. The definition of this term brings a situation of abuse of power and discrimination [26]. Although office politics can be seen as positive and negative attitude, in general term, this situation is always referred to be negative. The office politics become a positive game when the leader manipulates her/his power so that the subordinates follow her/his instruction for the purpose of achieving organizational effectiveness [27]. Thus, office politics becomes a good deed when it enhances subordinates' performance and organizational productivity laterally. On the other hand, office politics may look like a negative game when the leader uses her/his power for her/his personal agenda, which may deviate from organizational mission or create competition amongst leaders. Instead of employing a political game to build harmonious relationship, leader plays a negative political game to compete with her/his entrant, so that she/he can be seen better by top management or to build her/his own block of buddies that can help her/him to conquer resources. Office politics sometimes involve back-stabbing in order to achieve one's objectives [13–15]. Different employees have different views about politics in an organization. Even though politics brings a negative perception [10], but it is also needed to get cooperation from subordinates or peers to get job done because persuasion is used in politicking [26,28]. Political influence processes may also be used to maintain the status quo when change is ensured. Whether political behavior proves to be beneficial or harmful to the organization, it may depend more on how that behavior is perceived rather than reality [29]. It is possible that an individual's perceptions of and reactions to organizational politics may be culture specific and that further generalization of the theory of organizational politics should take into consideration the cultural context, in which each study is undertaken. Organizations with limited resources have been known to experience heightened levels of politicking among members, because the key actors within the organization often jostle to have a fair share of the limited resources for themselves and their units [8].

Office Politics and Performance Appraisal

Employees do not trust the performance appraisal result when organizational politics become the main issue in an organization. This was one of the main conclusions of Sharabi et al. comparative study of high-tech workers and public workers [30]. They also found that the lack of transparency, especially in the public sector, made the employees not fully satisfied with promotional activity and performance appraisal. Hence, in general, it can be said that employees respond negatively to work conditions for instance performance management that is influenced by politics. Fairness becomes the central intention amongst employees especially in performance appraisal process [31]. In addition, Longnecker saw that organizational politics can be a potential bias in performance appraisal because it involves abuse of power and discrimination [16]. Employees always have an optimistic view and believe that their performance is going to be evaluated with justice by their immediate superior. Hence, every superior should avoid abuse of power and discrimination when executing performance appraisal. Tziner et al. have demonstrated three discriminant factors that represent politics in performance appraisal [32]. Among them are manipulation to acquire benefits, attaining and exercising control and interpersonal issues. One of goals of this work is to evaluate whether Malaysian company also experiencing the same discriminant factors in performance appraisal as reported elsewhere [32–34].

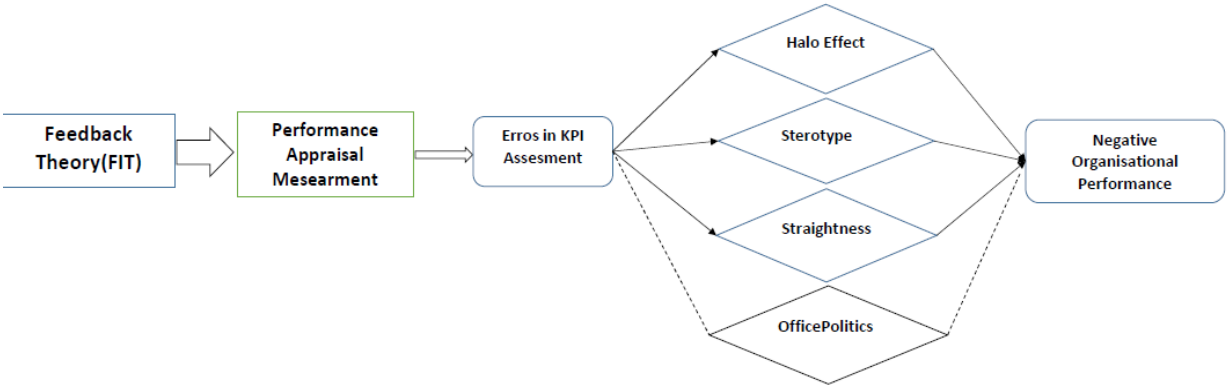

Figure 2. The research conceptual flowchart. Source: Authors.

Last but not least, this work fills up the theoretical and knowledge gaps in the literature since most of the recent and extant literature focused on the biased KPI practices can negatively impact organizational performance. The available literature on Malaysian GLCs has demonstrated the effects of biased practices such as stereotype, recency, and halo effects on organizational KPI. Despite this, the definitions, dimensions, and effects of office politics remain unclear and require further examination to shed light on the various forms of biased behavior [13–15]. The recent literature has yielded mixed results and inconsistencies in the significance of previous findings. Therefore, redefining office politics within the Malaysian financial sector is contemporary critical demand. As shown in Figure 2, the manuscript methodology adopts an empirical research study to the conceptual effects of office politics errors on organization performance and to restructure the prospects of this criteria. Furthermore, this study demonstrates a developed new conceptual model about the definitions of office politics by adding three dimensions for these prospects, which drive to better understand the phenomena of office politics errors and performance appraisal. The developed practical and applicable model can be implemented in policy making and help achieve more advanced business practice approaches.

Methodology

Research Design, Population and Sample

This study was a quantitative type of research and parametric tests were used to identify the relationship between independent and dependent variables. For this study primary data through questionnaire distribution were employed. In determining samples of the study, the sampling frame was defined and was followed by stratification of samples. Once the stratified samples have been determined, random sampling procedure was employed to identify the respondents. Questionnaires were distributed to respondents to evaluate their perception on items used to measure each variable. Instruments involved in this study were adopted from various sources. To examine the reliability of the questionnaires, pilot study was pursued. The value of Cronbach Alpha (α) determined the reliability of each item constructed in the questionnaire. Items in the questionnaire were clustered into appropriate dimensions in variables. The factor analysis was employed to justify items that represent dimensions or factors of each variable considered. The population of the study involved Felda Berhad headquarters officers and administrative staff and the overall population for this study was nine hundred potential responders. By using the sampling determination table suggested by Kriejcie et al. [35], the sample size for this study was established at the level of 274, while, in total, 271 answers were obtained and used in this work.

Research Instrument

The research questionnaire employed 4-point Likert type scales to represent respondents' agreement to each question. This scale was named the forced-choice scale. Huges [36] and Roach [37] noted that the forced-choice scale produce a negative bias. Forced-choice rating helps to directly control the common overall bias by forcing the respondents to choose between descriptive items that have an equal amount of the bias components [37]. Normative scales are subject to central tendency bias, in which respondents avoid extreme responses, acquiescence response and social desirability responding [38]. Forced - choice instruments are designed to avoid these biases by forcing choice alternative in a way that reflects real life choice making [39]. Agreeing with this statement, by using Pratt Index, Ochieng et al. [40] found that scale bias increases with the increment in Likert scale but remains almost constant after the 4-point Likert scale. Forced-choice methodology was developed to control or eliminate deliberate fake responses [41]. A study by King et al. on evaluating performance by using

forced-choice scale found that respondents believed the scale was fair and valid [38]. They concluded that the forced-choice scale was successful according to all of the usual psychometric criteria. To examine the type of office politics in performance appraisal, this study has employed Questionnaire of Political Considerations in Performance Appraisal (QPCPA) constructed by Tziner et al. [32]. This instrument consists of twenty-five items with Cronbach Alpha value of 0.97. Poon [42] has utilized this instrument in the attempt to measure the effect of politics in performance appraisal on job satisfaction and turnover intention. Poon also found that QPCPA is highly reliable as Cronbach Alpha value scored was higher than 0.8. A pilot test was performed to identify the reliability of research instruments and to indicate whether the respondents understand the meaning of each item they were asked for in the questionnaire. Reliability was defined as a degree to which measurements are free from error [43] and therefore yield consistent results between multiple instruments of a variable [44]. High reliability indicates minimum error variance, when the test indicates high value in reliability; hence, the effect of errors of measurement has been reduced. In measuring the reliability of research instruments, the Cronbach Alpha's value was computed. The values lower than 0.6 were generally considered to be poor, while those in the 0.7 range were considered to be acceptable. The values above 0.8 were considered as good [45]. Hair et al. also indicated that generally, the lower limit for Cronbach Alpha is 0.70, hence for this work the same limited for Cronbach Alpha value was considered [44].

Results and discussion

Data Screening

Data screening was performed before pursuing further statistical analyses. In data screening, the normality and linearity of the data as well as the identification of missing data and outliers were made. Skewness and kurtosis values to test normality and scatter plot evaluation were used to test linearity. Data screening process was performed to explore the characteristics of the data [46] in order to answer questions related to the accuracy of data, missing data, pattern of the missing data, extreme responses, and to what extent the collected data meet the statistical assumptions. When the data violated the statistical assumptions, data transformation was performed as suggested elsewhere [47]. Hair et al. stated that the identification of outliers has to be carried out before processing the collected data [44]. According to Meyers et al., extreme or unusual values on a single variable or a combination of variables are called outliers [47]. Besides identifying the potential outliers, testing of the assumptions underlying most multivariate techniques including normality and linearity were also considered in this study.

Factor Analysis

Factor analysis was performed to identify the discriminant factors and convergent of items for QPCPA [44]. The purpose of factor analysis was to summarize the information contained in a large number of variables into smaller number of factor [43]. R factor analysis was used in this research as it analyzes a set of variables to identify the dimensions that are latent . According to Hair et al. [44], the minimum sample size to pursue factor analysis is 50, while Coakes et al. suggested 5 respondents for each variable [46]. In this study 7 variables were used, hence the minimum sample to employ factor analysis according to Coakes and Steed was 35. Before performing factor analysis, the anti-image correlation matrix, the Bartlett test and Kaiser-Meyer Olkin (KMO) measure were performed.

Data Analysis

The reliability and normality tests were performed before pursuing the factor analysis. The QPCPA instrument scored Cronbach Alpha value of 0.780. For normality test, the evaluation of Skewness and Kurtosis values has been performed. Both values for Skewness and Kurtosis were 0.671 and -0.460 respectively. Both values are in the range of ±1.96 which represents that the data was normal. The anti-image correlation matrix, that involves MSA and partial correlation tests, Bartlett test and Kaiser-Meyer Olkin measure to quantify the degree of intercorrelations among the variables were performed in this study too. In general terms, when a variable is identified as highly correlated with one or more variables, factor analysis for this particular variable becomes inappropriate. In inspection of the MSA, items with value that falls below the acceptable level of 0.5 should be excluded from the factor analysis [46]. According to Hair et al., in testing partial correlation, when the value of partial correlation is 0.7 and above, it can be considered as high and unacceptable [48]. In measuring MSA, items QPCPA 13, QPCPA 18 and QPCPA 24 were discarded as their values were below 0.5. The partial correlation values for all QPCPA items were well below 0.7, which indicates that all items do not overlap with others. The Bartlett test and KMO measure of sampling adequacy has been used to determine the factorability of the matrix as a whole. The Bartlett test is a statistical test for the presence of correlations among the variables. It provides the statistical probability that the correlation matrix has significant correlations among at least some

of the variables [44]. For Bartlett test, the level of statistical significance of ρ< 0.05 was considered. The KMO measure of sampling adequacy quantifies the degree of inter correlation among the variables and the appropriateness of factor analysis. Coakes et al. indicated KMO's acceptable value was above 0.5 [46].

Table 1. KMO and Bartlett's test values. *Source: Authors.*

Variable	**KMO Value**	**Bartlett's test of Sphericity (sig)**
Office Politics in Performance Appraisal	0.782	0.00

Table 1 shows QPCPA for 0.782 of KMO value. In addition, Bartlett's test was significant as ρ<0.05. These score values enable the researcher to perform factor analysis.

Factor Identification

In order to identify a number of factors, this study employs latent root criterion. In latent root criterion, eigenvalues were examined. According to Hair et al. [44] and Meyers et al. [47], factors with eigenvalues greater than one were considered significant. In addition, Hair et al. [44] suggested that it is common to consider a factor or combination of factors that accounts for 60% of the total variance as satisfactory. In order to achieve a simpler and pragmatically more meaningful factor solution, factor rotation was considered in this study. In addition, the varimax rotation was employed too in order to extract factor accounts for the most variance. Varimax rotation is a process in orthogonal rotation method [44]. Orthogonal factor rotation is a statistical concept indicating that two or more factors are independent to one another [47]. Varimax maximizes the sum of variances of required loading of the factor matrix. Varimax seems to give a clearer separation of the factors [44]. Varimax rotation was used because this method is focused on achieving simple structure [47] and shows a more meaningful factor pattern [44]. As given in Table 2, 6 factors scored eigenvalue greater than one. Total cumulative eigenvalues percentage for these three factors was 74.509%. Hence, the Factor Analysis allowed establishing 6 discriminant dimensions for QCPCA.

Table 2. Eigenvalues for Politics in Performance Appraisal (Extraction Method: Principal Component Analysis). *Source: Authors.*

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**			**Rotation Sums of Squared Loadings**		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
Dimension	7.475	33.978	33.978	7.475	33.978	33.978	5.744	26.108	26.108
	4.138	18.810	52.788	4.138	18.810	52.788	3.739	16.993	43.101
	1.356	6.166	58.953	1.356	6.166	58.953	2.366	10.754	53.856
	1.281	5.822	64.775	1.281	5.822	64.775	1.722	7.828	61.684
	1.093	4.966	69.741	1.093	4.966	69.741	1.502	6.828	68.513
	1.049	4.768	74.509	1.049	4.768	74.509	1.319	5.997	74.509

To identify the factor loadings, the guideline suggested by Hair et al. [44] was used. Hair et al. indicated that when the loadings are ± 0.50 or greater, they can be considered practically significant [44]. Therefore, in identifying content of each dimension, items with factor loading value ± 0.50 and above were clustered in the same factor. Items that have a loading factor value below factor loading (for this particular study ± 0.50) and do not belong to any factor can be dropped off in an effort to refine and reduce the scale [49]. In addition, items that have a cross loading with two or more factors were discarded. Cross loading is an item that has overlapping variance with more than one factor [50]. Cross loading item occurs when the item was poorly written [50]. In addition, according to Meyers et al. [47], one item cannot represent a particular factor.

Table 3 demonstrates 6 factors that were constructed by rotated component matrix. Factor 1 comprised of 9 items including "Supervisors produce accurate performance ratings only to the extent that they perceive that this is the norm in the organization", "Supervisors avoid giving a low performance rating because they fear violent behavior on the part of their employees" and "Supervisors' performance rating is effected by the extent to which employees are perceived as sharing the same basic values as they do". Factor 2 consisted of only 5 items including

"Supervisors give performance ratings that will make them look good to their superiors" and "Supervisors are likely to give an inflated performance rating in order to avoid negative/uncomfortable feedback sessions with their employees". Factor 3 consisted of 3 items including "Supervisors' performance rating reflects in part their personal liking or disliking of the employees". Factors 4, 5 and 6 have only one item each; therefore, these factors were discarded from further analysis.

Table 3. Rotated Component Matrix for Perception of Politics (Extraction Method: Principal Component Analysis, Rotation Method: Varimax with Kaiser Normalization). *Source: Authors.*

	Component					
	1	2	3	4	5	6
QPCPA16	0.837					
QPCPA3	0.822					
QPCPA25	0.788					
QPCPA7	0.772					
QPCPA4	0.728					
QPCPA22	-0.675					
QPCPA19	0.674					
QPCPA5	-0.647					
QPCPA17	0.646					
QPCPA10		0.862				
QPCPA15		0.833				
QPCPA11		0.813				
QPCPA9		0.645				
QPCPA1		0.629				
QPCPA21			0.746			
QPCPA8			0.728			
QPCPA6			0.688			
QPCPA23				0.774		
QPCPA12					0.783	
QPCPA14						
QPCPA20						0.823
QPCPA2						

To label the factor, this study has followed the approach given by Hair et al. [44]. They indicated that the label is intuitively developed by the researcher based on its appropriateness for representing the underlying dimensions of a particular factor. The variables with higher loadings are considered more important and have greater influence on the name or label selected to represent a factor. After determining discriminant factors and its convergent items, this study performed a reliability test again. Table 4 reveals the Cronbach Alpha (α) value for office politics in performance appraisal after factor analysis process. The first factor for office politics in performance appraisal consists of nine items and Cronbach Alpha value was 0.595. After discarding the item QCPCA22, the value increased to 0.760. This factor has been called "Acquire Benefit". For factor 2, this particular factor consists of 5 items and the Cronbach Alpha for this factor was 0.827. Because of the items for this factor reflects relationship between superior and subordinates, this factor was named "Human Relation." Factor 3 consists of three items with Cronbach Alpha value of 0.725 and this factor was named "Control". Hence, these three factors representing office politics in performance appraisal are reliable and are given in Table 4.

Table 4. Reliability Test after Factor Analysis. *Source: Authors.*

Office Politics in Performance Appraisal	**Cronbach Alpha (α) after factor analysis**
Factor 1 (Acquire Benefit)	0.760
Factor 2 (Human Relation)	0.827
Factor 3 (Control)	0.725

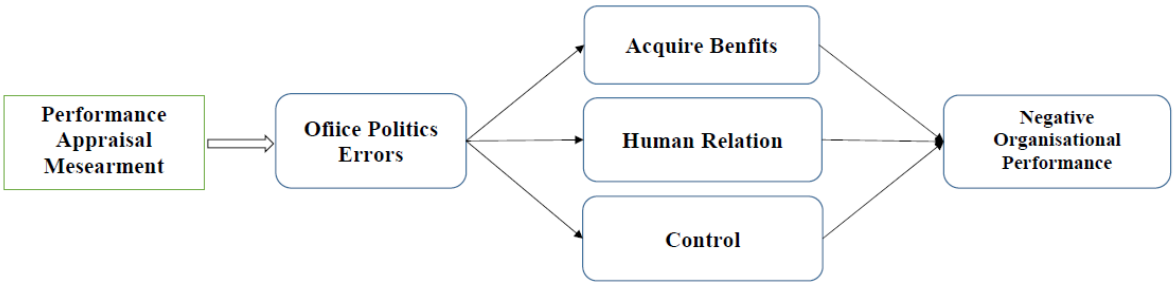

Figure 3. The conceptual model for office politics errors factors. *Source: Authors.*

As shown in Figure 3, the three discriminant factors namely Acquire Benefit, Human Relation, and Control were extracted. Acquiring benefits represents the effort of supervisor to fulfill her/his need to be looked like a good supervisor. In other words, in human relations, the supervisor uses performance appraisal to maintain good relationships with her/his subordinates. The last dimension of politics in performance appraisal obtained in this study is control. This dimension represents the attempt of supervisor to motivate or even to threaten her/his subordinates to show their best performance throughout the evaluation year.

Political masks in a performance appraisal also affect its effectiveness. Many managers are willing to manipulate performance appraisals for political purposes. The design of such performance appraisals leaves very crucial assessment procedures to suit certain political interests. Management of employees' performance always becomes doubtful in terms of fairness and justice. Ferris et al. [11] indicated that performance management is often political in nature. The existence of political games in performance management may reduce employees' morale towards their employment [26]. This result is in line with the dimensions of politics in performance appraisal suggested by Tziner et al. [44]. Previous study by Tziner et al. [44], have extracted two discriminant factors for politics in performance appraisal, while Poon [42] has extracted only one. Tziner et al. [44] called it "manipulation to acquire benefits, attaining and exercising control and social or interpersonal", while Poon [42] has named it as politics in performance appraisal as motivational intention. It is plausible that the supervisor uses political activity to sustain her/his own benefits by giving a good rating in appraising her/his subordinates' performance. She/he hopes that she/he will look good by the top management even though she/he manipulates her/his subordinates' performance rating. The supervisor also does not want to create conflicts either with his subordinates or with the top management. Hence, she/he is willing to abuse her/his power and give unreasonable ratings to her/his subordinates, so that she/he will not be questioned by both parties. This lessens the creation of conflict between the supervisor and her/his subordinates and helps sustain the harmonious human relation. In addition, by using her/his authority in performance appraisal the supervisor can manipulate her/his power to discriminate any subordinate that she/he dislikes by threaten them with poor rating when the subordinate refuse to follow her/his lead or in other word, the performance appraisal is used as a control mechanism. Therefore, the performance appraisal is generally used as a tool for the supervisor in playing her/his political game to gain benefits, maintaining human relation, and controlling subordinates' behavior.

Acquiring benefits represents the effort of supervisor to fulfill her/his need to be looked like a good supervisor. A leader tends to be lenient in appraising his employees' performance even if the employees show poor performance because when she/he gives her/his employees a high mark in performance appraisal, she/he will be seen as a good leader. In acquiring benefits, although the subordinate does not show good performance throughout the year but only showing better performance in appraisal month, leaders may appraise his employees' performance based on the recent behavior. A leader tends to ignore her/his employees' performance throughout the year. In addition, the leniency in performance appraisal rating avoids violent behavior amongst employees. Hence, this leniency and evaluation of employee bias on a recent behavior in performance appraisal, which are biases in performance appraisal, can be manipulated by a leader to get support from her/his subordinates to achieve her/his self-interest or she/he want to be looked as a good leader. In acquiring benefits, when the employee is really showing a good performance, the leader shows his truthfulness in rating the employee's performance. Some employees may show an extraordinary performance; hence, the leader should escalate the employee's rating to motivate the employee to sustain his/her best performance. The increment of performance rating for extraordinary performance may encourage the employees to show their creativity in performing their works. Leaders who assign an accurate rating to the right performance do not

breach the norm in organization as this avoids disapproval by her/his peers. In judging an employee who is a good performer, the leader always does the appraisal according to the right source of information. In this situation, the leader pretends that she/he upholds justice, which becomes a shared value in an organization. In human relation factor, the supervisor uses performance appraisal to maintain good relationship with her/his subordinates. By appraising the employee's performance with leniency, the supervisor hopes that she/he can minimize the employee's dissatisfaction. This in turn may create a conflict. To reduce the conflict in her/his department, a leader pretends that she/he gives an accurate appraisal because when the employees find out that they score poor result in performance appraisal, the leader can be penalized. A leader abuses her/his power through avoiding giving performance ratings that may antagonize her/his employees. In human relation factor, the leader may appraise the employee's performance according to the quality of leader-employee personal relationship. When the employee is the leader's buddy, she/he may be rated with a high appraisal result. The leader is likely to give an inflated performance rating in order to avoid negative feedback by her/his employees. The last dimension of politics in performance appraisal is control. This dimension represents the attempt of supervisor to motivate or even to threaten her/his subordinates to show their best performance. When the employees can show their good performance, the leader can be considered by the top management as efficient. In control factor of performance appraisal, the leader's performance rating reflects in part her/his personal liking or disliking of her/his employee. The employees tend to be rated by evaluating their abilities to inspire their works and creativity enthusiasm to the leader who rates their performance. In some circumstances, when the leader dislike a targeted employee he/she may give low performance rating just to encourage the employee to leave the organization. Usually, the employee who is victimized by the leader is an employee who cannot get along with the leader. In this case, the leader abuses his power to discriminate a distrust employee.

Impact

The presented work showed that organizational politics is a tool used to play with the human resources in the Malaysian organization. These observations can be broadly extended to other nations as well as on different economic sectors. However, to better address this issue, more advanced studies should be done. It can be carried out for different sectors of the economy as well as a wide scope of population should be considered. Nevertheless, the most relevant aspects, which should be considered in the further valorization of this work is that to avoid negative implication of organizational political games, the supervisors should be attentive listener to keep a close contact with the employees. The superior should also guide the gathering of information, judgments and opinions. Also, the leader should foster a productive dialog and bring in refreshing ideas that employees have not thought of. To achieve this, the proper communication channels should be used beyond the political games, based on ethical tools to perform a proper monitoring and assessment of the employees' achievements. By using this tool, the leader will be seen as a stable anchor and a tower of strength who maintains and creates calm. This, in turn, will drive the leader to be seen as a moral guide, who by applying high moral standards and influences the employee's ethics do not preach or lecture. Finally, this results in turning the political games in the organization structure into a tool to share knowledge and skills with employees in order to improve their capabilities.

Conclusions

Politic in workplace becomes a customary phenomenon in organization. Many previous studies have exhibited the negative impact of this phenomenon on workers' performance [51]. Among them are halo effect, stereotyping, leniency, strictness, similar to me error and recent behavior error. With the evolution of office management, politics in organization has become the new factor that may affect performance appraisal activity. This present study has successfully extracted three factors that represent politics in performance appraisal namely acquire benefit, human relation, and control. As stated by Drory [52], employees who are in supervisory or middle management positions normally enjoy greater authority and autonomy. As a competition of power exists in managerial level, a political game will become a weapon to dominate the decision-making process. Top management must control the existence of power abuse, employee discrimination and office bullying, which are among the activities performed in political games because office politics is always seen as bringing a bad impression to employees. It drives to employee's frustration, dissatisfaction, and subordination. Hence, fairness and justice must become the indispensable factors in appraising employees' performance. It is plausible that political activity is used by the supervisor to sustain her/his own benefits by giving a good rating in appraising his subordinates' performance. She/he hopes to be considered as a good leader by the top management even though she/he manipulates her/his subordinates' performance rating. The supervisor also does not want to create conflicts either with his subordinates or with the top management. Hence, she/he abuses her/his power

and gives unreasonable ratings to her/his subordinates, so she/he is not questioned by both parties. This reduces the creation of conflict between the supervisor and his subordinates and helps to sustain the harmonious human relation. In addition, the supervisor, by using her/his authority in performance appraisal, can also abuse her/his power to discriminate against any subordinate that she/he dislikes by threatening them by poor rating. In this case, the performance appraisal can be seen as a control mechanism. Therefore, the performance appraisal is used as a tool for the supervisor in playing her/his political game to gain benefits, maintaining human relations and controlling subordinates' behavior.

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COMPARATIVE ANALYSIS OF DIFFERENT INVERTERS AND CONTROLLERS TO INVESTIGATE PERFORMANCE OF ELECTROSURGICAL GENERATORS UNDER VARIABLE TISSUE IMPEDANCE

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Highlight
Reduction of heat dissipation and total harmonic distortion of electrosurgery generators by using multilevel inverters and fractional order PID.

Abstract
Electrosurgical generators (ESGs) are currently the most widely used surgical technology for clinical operations. The main disadvantage of ESGs is their output power is irregular due to the variable tissue impedance. The heat dissipation caused by the high amount of thermal energy generated leads to medical complications for both patient and surgeon. In this research, various inverter topologies and power controllers are investigated to specify the best structure that ensures best performance. The type of inverter topologies investigated are three level and five level, while the PID structures investigated are integer order (IO-PID) and fractional order (FO-PID). The simulation results indicate that FO-PID with five level inverters is better than IO-PID with three level inverters in terms of minimum heat dissipation rate and THD of the output voltage and current.

Keywords
electrosurgical generator; tissue impedance; multilevel inverter; integer order-PID; fractional order-PID.

Introduction
Several centuries ago, heat was used to halt bleeding, and as technology evolved, a number of devices were invented that employ electrical energy to control bleeding and heal tissues. Modern electrosurgery is now one of the most extensively used surgical procedures [1]. Electrosurgery uses high-frequency electric currents to cut and dry target tissue (radio frequencies). This approach is used to achieve clinical outcomes with less blood loss and less time than typical operations [2]. Electrosurgery works by sending a high-frequency electric current through a conductor to the target tissues, where it is transformed into heat energy. The electrosurgical functions of cutting, coagulation, and drying are dependent on the kind of current wave, current density, tissue conductivity, electrode size, and time [3,4]. The ESG sends electrical energy to the tissues via electrodes

(monopolar and bipolar). The difference between the two varieties lies in the positioning of the active and return electrodes. In the monopolar, the active electrode connects to the generator to provide current to the tissues, while the return electrode connects to one region of the patient's body to send current back to the generator. In a bipolar electrode, the active and neutral electrodes of a bipolar electrode are close together, and the electric current flows via one of them, returning to the generator through the other, without going through the patient [5]. Most of the 230 million surgical procedures performed worldwide each year rely on electrical energy, which benefits both the patient and the medical team by speeding up cutting tissues and reducing medical team effort [6]. However, the irregular output power and high heat dissipation of ESG units can lead to several medical complications, including:

- Burns both the patient and the surgeon if the device is not properly controlled or if the electrodes are in contact with the patient's skin for an extended period. These burns can range from superficial skin burns to deeper tissue damage.
- The high heat generated by ESG units can cause tissue damage beyond the intended surgical site, leading to unintended injuries and complications.
- ESG units can cause involuntary muscle contractions and nerve stimulation.
- ESG units can produce smoke and fumes that can be harmful to both the patient and the surgical, which leads to respiratory problems, such as eye irritation.

The reason for this is due to vary the ESG's load (vital tissues), which, the tissue's structure and qualities, that are present in the form of impedance. This change in load causes a change in the ESG's output power directed at the target part, which does not match the power parameters specified by the specialist medical team to achieve the desired clinical effects [7]. As a result, it was necessary to find appropriate solutions to this problem, and the most optimal and appropriate solution, based on the findings of the studies in this field, was to develop an intelligent control system that would regulate the generator's output power independently of the medical team.

Many studies applied several control methods and compared them to find the best performing ESG. Perhaps some studies are still based on studying this problem, whose goal is to obtain the best performing ESG, as shown in [7–9]. These studies did not address this issue, which is reflected in the thermal effects of the generator, even if they addressed the issue of changing the ESG's output power due to changes in tissue impedance. Thermal diffusion is another issue that electrosurgical techniques address. Thermal damage is one of the most dangerous concerns in electrosurgical treatments, causing burns to the subject tissues during surgery or complications following surgery, some of which are serious enough to cause patient death. When studying this problem to find appropriate solutions. The type of biological tissue undergoing surgery, the distance between the tissue and the active electrode, the position of the returning electrode, the position of the operating cable, the properties of steam and gas, and the type of tool used to perform surgery are all factors that contribute to the complexity of the problem [10]. Several research studies have studied the problem and developed solutions. In [10], the researcher proposed using thermometric sensors to limit or eliminate thermal spread, which he demonstrated using a piece of chicken meat. In [11], the researcher suggested employing a thermal management system (TMS) to limit heat dissipation in monopolar electrosurgical operations, with positive results. To prevent thermal damage and tissue adhesion in minimally invasive surgery, the researcher employed ultrasonic vibration-assisted approach [12]. ESG should be studied and analyses in a realistic manner and tested on different loads, not just one, to verify the validity and strength of the improved methods used to improve its performance. Although the previous research focused on regulating the ESG's output power or reducing tissue thermal dissipation, their methods were not applied to the generator in its non-ideal state, as there are no electronic circuits that work perfectly 100% of the time. Additionally, the results were validated using a single load model. The load, on the other hand, is changeable due to the fact that important tissues vary in terms of tissue density, age, and sex. In [13], the researchers studied and examined the buck converter circuit, which is one of the device's electronic circuits in a non-ideal state. Tests on the examined circuit demonstrated that its behavior at 100 kHz is better from an economic and practical standpoint. Similarly, three different age and gender loads (child, male, and female) were explored as test models for the generator design process. This research provided a more in-depth analysis of the generator design process, but it provided no feasible ways to increase the generator's performance, as the data showed that output power changes with each of the three loads, as well as did not contribute to reducing heat dissipation.

This paper aims to develop and build an ESG that is more realistic and avoids the majority of possible issues. This study relies on research [13] in designing the ESG with a switching frequency of 500 kHz, as well as on the three loads considered, which include different layers for children, males, and female's tissues. The ESG's

output power is regulated using the standard IO-PID and FO-PID controllers as well as using optimal IO-PID and FO-PID controller's parameters. The ESG's output voltage and current waveforms are improved by replacing the three-level typical inverters with a five-level advanced inverter, which reduces or eliminates tissue thermal dissipation.

Methods

The closed-loop control system of ESG is designed in this work employing controllers of integer order PID (IO-PID) and fractional order PID (FO-PID). The particle swarm optimization (PSO) technique is then used to fine-tune the settings of each controller type in order to obtain the best values for the parameters that control the ESG's output power. In addition, to reduce heat dissipation, an advanced 5 multilevel inverter circuit was employed instead of the traditional H-bridge inverter circuit used in most research to design the ESG. The performance of the ESG is evaluated using a variety of control modes and inverter circuits, which are proposed in this paper.

Effect Temperature on the Tissue

The typical body temperature is approximately 37°C and may exceed 40°C. At these temperatures, the cellular structure of tissues is good. When the temperature is increased to between 60 and 100°C, the proteins solidify, resulting in the formation of clots and hence the coagulation process. When temperatures are above 100°C, the fluid inside the cells boils, causing the cell walls to break; this is referred to as the cutting process. Concerning the highest temperatures, this could result in the breakdown of organic molecules, resulting in what is known as carbonation [14,15]. Temperature increases beyond a predetermined threshold cause cellular damage to tissues [16,17]. Additionally, thermal diffusion caused by elevated temperatures can cause injury to adjacent organs such as the bladder, ureters, and intestines [18]. It's worth noting that around 4000 people every year suffer burns produced by electrosurgery, and 70% of these injuries are not noticed during surgery, but rather afterward, resulting in illness or death. This adverse effect is not confined to the patient, but also to the medical team, as substantial financial compensation is provided for such injuries [19,20]. Figure 1 displays some of the damage done by the ESG. The amount of thermal energy generated in biological tissues during electrosurgery can be calculated based on Joule's law of energy [14,21,22], which states that:

(1) $$Q = P \times t$$

where P can be written as:

(2) $$P = V \times I$$

where:
Q - is energy heat in joule (*J*)
P - is the output power in watt (*W*)
t - is the time interval for current to flow in second (Sec)
V - is the output voltage in volt (*V*)
I - is the output current in ampere (*A*).

According to the preceding two formulas, the amount of heat energy relies on the voltage, current, power, and time, also, the output power of the ESG is voltage and current dependent. As a result, it is possible to enhance the ESG's performance and reduce or eliminate thermal diffusion by controlling the ESG's output voltage and current. This is accomplished by optimizing the inverter circuit utilized in the ESG's construction, which is responsible for the ESG's output.

(a) (b) (c)

Figure 1. Injuries caused by the heat dissipation in electrosurgery. *Source: (a) [23]; (b) [24]; (c) [10].*

Tissue Bioimpedance Models

The biological electrical impedance of tissues can be defined as a measure of the opposition shown by materials resisting the flow of AC cur-rents at different frequencies and expressed physically by electrical impedance. This impedance reflects the clinical condition of the tissues re-quired for the clinical procedure [23]. The biological impedance can be calculated by Eq. 3 [24].

(3)
$$Z_{Tissue} = \frac{1}{\frac{1}{R_p} + \frac{j}{X_c}}$$

where:

Z_{Tissue} - is bioimpedance of tissue in Ω

R_p - represents water and electrolyte fluids resistance in the extracellular

X_c - is capacitive reactance in Ω.

Inverter Circuit

An inverter is an electrical circuit that converts direct current to alternating current at the desired output voltage and frequency. However, the inverter circuit suffers from significant conversion losses and operates at a low practical efficiency [25]. The traditional inverter circuit generates square-shaped output voltage and current waves. This type of wave contains a significant proportion of total harmonic distortion (THD), which is undesirable in electrical circuits because it causes distortions in the current and voltage waveforms, as well as an increase in temperature and loss [26,27]. To overcome these issues, a multi-level inverter can be utilized to improve both the voltage and current waveforms, as well as the THD [25,28,29]. Figure 2 shows the H-bridge conventional inverter circuit, whose design and implementation were studied in the research [13]. Figure 3 shows the advanced 5 multilevel inverter circuit that is proposed in this study. The Fourier series method is used to calculate the ratio THD of the output for each type of inverter circuits.

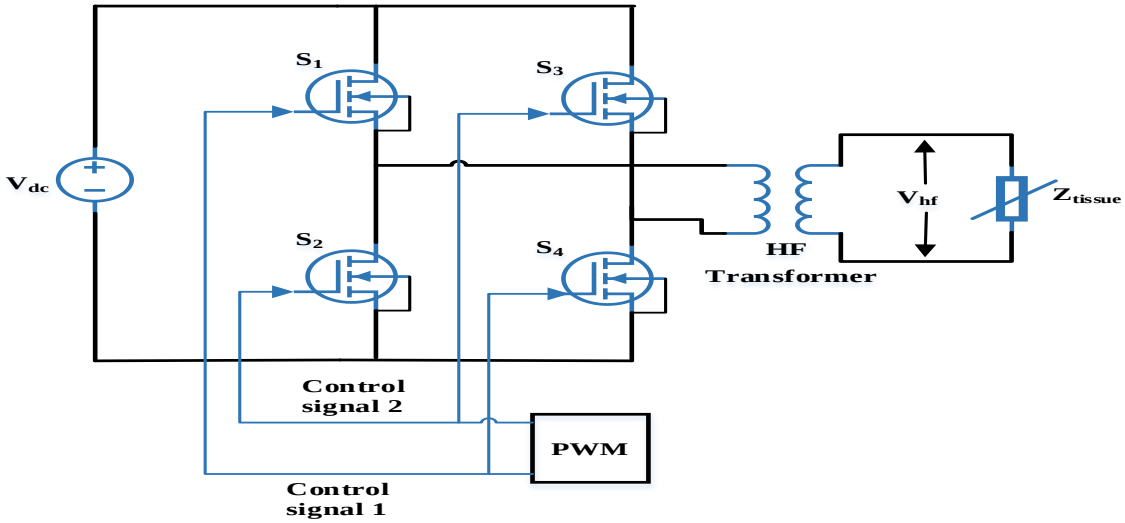


Figure 2. H-bridge conventional inverter circuit. *Source: [13].*

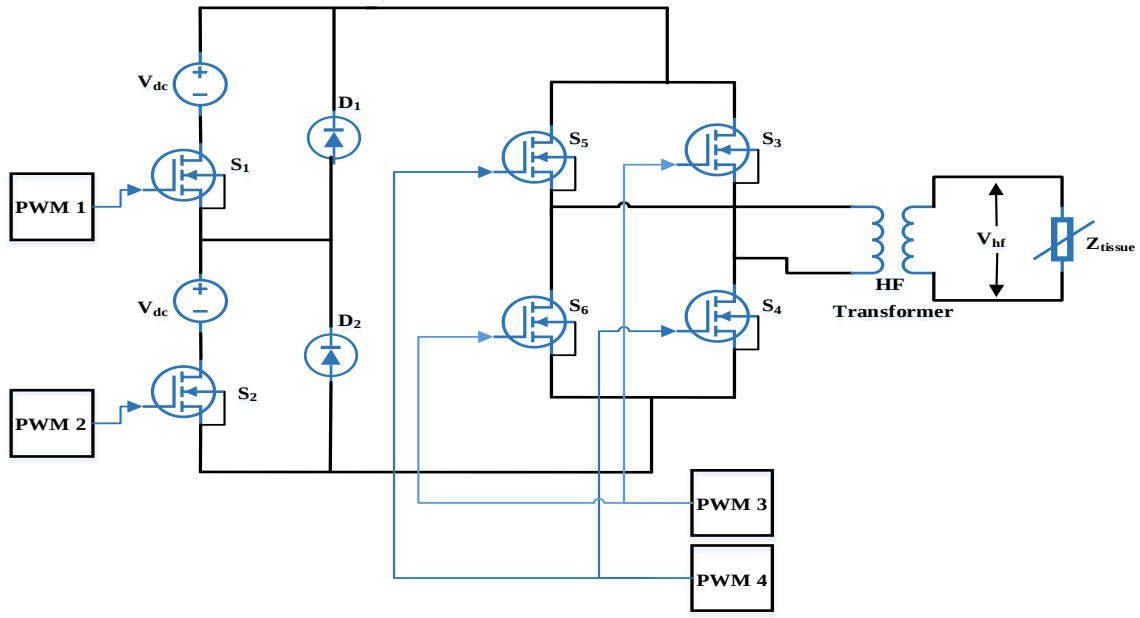


Figure 3. Advanced 5 multilevel inverter circuit. *Source: Authors.*

Total Harmonic Distortion (THD)

Based on Fourier series equation shown in Eq. a, THD of the output voltage and current for the conventional H-bridge and advanced inverter circuits of the ESG can be determined as follows :

(4) $$V_{HF}(Z_{Tissue}, nwt) = \frac{a_\circ}{2} + \sum_{n=1,2,3,\ldots}^{\infty} a_n \cos(nwt) + b_n \sin(nwt)$$

- Qualitative analysis for THD in case H-bridge inverter circuit

(5) $$a_\circ = \frac{2}{T}\int_0^T V_{HF}(Z_{Tissue}, nwt)dwt\,, a_\circ = 0$$

(6) $$a_n = \frac{2}{T}\int_0^T V_{HF}(Z_{Tissue}, nwt)\cos(nwt)\,dwt,\ a_n = 0$$

(7) $$b_n = \frac{2}{T}\int_0^T V_{HF}(Z_{Tissue}, nwt)\sin(nwt)\,dwt,$$

when n is even then bn = 0 and when n is odd bn is

(8) $$b_n = \frac{4V_{dc}(Z_{Tissue})}{n\pi}$$

subsisting Eq. 5, 6, and 7 in Eq. 4

(9) $$V_{HF}(Z_{Tissue}, nwt) = \sum_{n=1,2,3,\ldots}^{\infty} V_n \sin(nwt)$$

(10) $$I_{HF}(Z_{Tissue}, nwt) = \sum_{n=1,2,3,\ldots}^{\infty} I_n \sin(nwt)$$

(11) $$V_n = \frac{4V_{dc}(Z_{Tissue})}{n\pi}$$

(12) $$I_n = \frac{V_n}{(Z_{Tissue})_n}$$

(13) $$THD_v = \frac{\sqrt{\sum_{n=2}^{\infty}(V_{n,rms})^2}}{V_{1,rms}}$$

(14) $$THD_i = \frac{\sqrt{\sum_{n=2}^{\infty}(I_{n,rms})^2}}{I_{1,rms}}$$

- Qualitative analysis for THD in case advanced inverter circuit

(15) $$a_\circ = \frac{8}{T}\left[\int_{\alpha_1}^{\pi-\alpha_1} V_{HF}(Z_{Tissue}, nwt)dwt\right] + \frac{4}{T}\left[\int_{\alpha_2}^{\pi-\alpha_2} V_{HF}(Z_{Tissue}, nwt)dwt\right], a_\circ = 0$$

(16) $$a_n = \frac{8}{T}\left[\int_{\alpha_1}^{\pi-\alpha_1} V_{HF}(Z_{Tissue}, nwt)\cos(nwt)\,dwt\right] + \frac{4}{T}\left[\int_{\alpha_2}^{\pi-\alpha_2} V_{HF}(Z_{Tissue}, nwt)\cos(nwt)\,dwt\right], a_n = 0$$

(17) $$b_n = \frac{8}{T}\left[\int_{\alpha_1}^{\pi-\alpha_1} V_{HF}(Z_{Tissue}, nwt)\sin(nwt)\,dwt\right] + \frac{4}{T}\left[\int_{\alpha_2}^{\pi-\alpha_2} V_{HF}(Z_{Tissue}, nwt)\sin(nwt)\,dwt\right]$$

when n is even then $b_n = 0$ and when n is odd b_n is

(18) $$b_n = \frac{4V_{dc}(Z_{Tissue})}{n\pi}[\cos(n\alpha_1) + \cos(n\alpha_2)]$$

subsisting Eq. 14, 15, and 16 in Eq. 4

(19) $$V_{HF}(Z_{Tissue}, wt) = \sum_{n=1,2,3,\ldots}^{\infty} V_n \sin(nwt)$$

(20) $$I_{HF}(Z_{Tissue}, nwt) = \sum_{n=1,2,3,\ldots}^{\infty} I_n \sin(nwt)$$

where:
a_n and b_n - are Fourier series components
n - is the number of orders for the harmonics
V_{dc}, V_{HF}; I_{HF} and Z_{Tissue} - are the DC input voltage
high-frequency AC output voltage
high-frequency AC output current and impedance tissue respectively
THD_v and THD_i - are the total harmonic distortion of the output voltage and output current respectively
α_1 and α_2 - are firing angles

PID Controllers

A fractional PID controller is a type of PID controller that is an extension of the conventional PID controller. The fractional order controllers are less sensitive to changes in the controlled system's and controller's characteristics. In ESG, an accurate control system is built using an integer order-PID (IO-PID) controller and a fractional order-PID (FO-PID) controller. IO-PID controller consists of three types of control i.e., Proportional, Integral, and Derivative control. FO-PID controller has two extra parameters, λ, and μ (orders of integration and differentiation), which make the controller more adaptable. Figure 4 shows a block diagram for the two controllers. The system transfer function in the continuous s-domain for IO-PID and FO-PID are given in Eq.20 and Eq.21 respectively, where Kp is the proportional gain, Ki is the integration coefficient and Kd is the derivative coefficient, λ and μ are the orders of integration and differentiation respectively [30,31].

(21) $$G_{IO-PID}(S) = K_p + \frac{K_i}{S} + K_d S$$

(22) $$G_{FO-PID}(S) = K_p(1 + \frac{K_i}{S^\lambda} + K_d S^\mu)$$

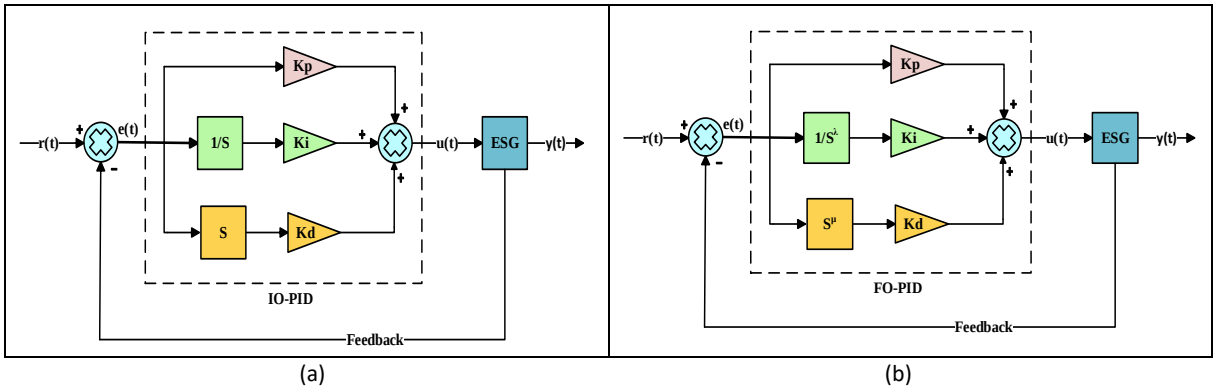


Figure 4. (a) IO-PID controller, and (b) FO-PID controller. *Source: Authors.*

The conventional particle swarm optimization (PSO) algorithm is used to adjust the parameters of each of the two types of controllers to get the best values for the parameters to achieve the desired goal. Figure 5 shows the block diagram of the IO-PID and FO-PID controllers with the PSO algorithm. It is worth noting, that the control system of both types of IO-PID and FOPID is applied to the two ESG, i.e., the ESG that is designed using the H-bridge traditional inverter circuit and the generator that is designed using the advanced 5 multilevel inverter circuit, to regulate the output power of each generator and watch the behavior of each type of the two generators and the affected of their practical properties.

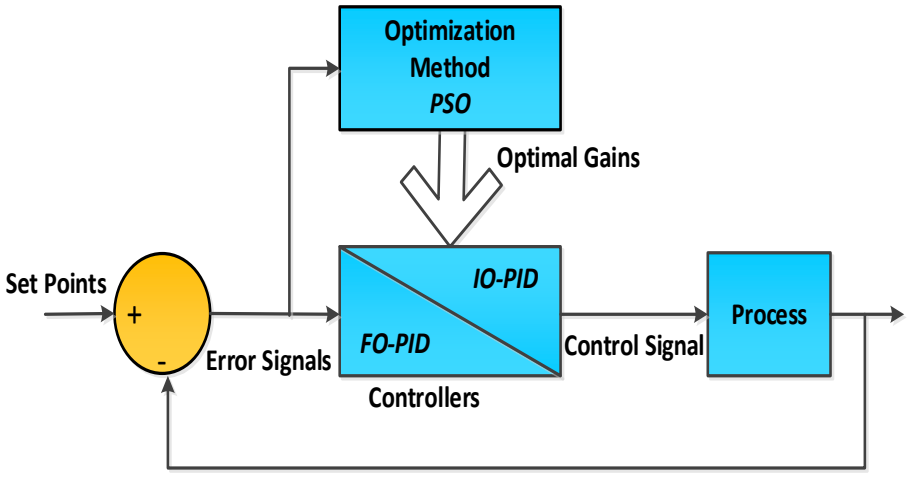


Figure 5. Block diagram of the PSO with IO-PID and FO-PID controllers. *Source: Authors.*

Results and discussion

The design and implementation of the ESG is done by MATLAB/SIMULINK environment. In this study, must be put two practical steps for the design process in order to reduce or eliminate the defects faced by the ESG, the most important of which is the irregularity of the output power to the ESG due to the nature of the variable impedance of the tissues, as well as the heat dissipation that occurs when performing the surgery, which causes burns or other side effects for the patient. The following are the first and second steps in the design procedure: In a closed-loop architecture, the ESG's output power can be controlled by a control unit even if the tissue impedance changes. To avoid harming the patient or medical staff, calculate the ESG's thermal energy output and, if necessary, lower it to a level that is safe for the patient. As IO-PID and FO-PID control units were used in this study, their performance was compared to see which type of controller performed best to improve the ESG's performance. The PSO algorithm was used to find the best values for controller parameters IO-PID and FO-PID. The control system is designed in the ESG, whose design and implementation were studied in the research [13], where the generator is designed at a frequency of 500 kHz and the ESG's output power (the desired amount of power set by the surgeon) is set to around 100 W a reference value to compare to the measured value of the output power. Additionally, the ESG's performance is evaluated after it has been equipped with the control system under three different loads (child, male, and female). The simulation results

demonstrate the behavior of each control type for various layers of each load type. The OV and Ts of the ESG's output power signals are compared. After developing an ESG with a control mechanism for regulating the generator's output power. The second phase in the design process is to calculate the quantity of thermal energy generated by the generator in order to determine the effect of the various types of controllers employed in the generator. Furthermore, the controller's ability to regulate the ESG's output power is considered. Thermal energy is computed for each of the layers using Eq. 1 for the three loads in the transient situation. Additionally, the percentage of thermal reduction for each type of controller can be determined using Eq. 22.

(23) $$RH = \frac{Q_{IO-PID} - Q_{measured}}{Q_{IO-PID}} \times 100\%$$

where *RH* denotes the degree of heat reduction. $Q_{IO\text{-}PID}$ (in Joules) is the thermal energy for each layer when using an IO-PID controller. This value is used as a reference for comparing thermal energy values for various controller modes. $Q_{measured}$ (in Joules) represents the thermal energy for each layer in other controller modes, such as standard FO-PID and optimal IO-PID or FO-PID controller settings. When the heat reduction ratio was calculated, it was found to be extremely low in all types of controllers. Additionally, the THD was quite high. As a result, it was required to identify suitable solutions to this problem. One alternative is to replace the conventional H-bridge inverter circuit with an advanced five-level inverter circuit. The ESG is constructed using a five-level multilevel inverter circuit. The same control system technique was used to design the ESG, utilizing a typical inverter to manage the output power under the same load mode. The simulation results demonstrate a significant improvement in the waveform for both the voltage and current outputs. When an advanced 5 multilevel inverter circuit was employed to design the ESG, the ratio THD was significantly reduced. Figure 6 illustrates the waveforms for the ESG's output voltage and current when a traditional inverter and an advanced 5 multilayer inverter are utilized.

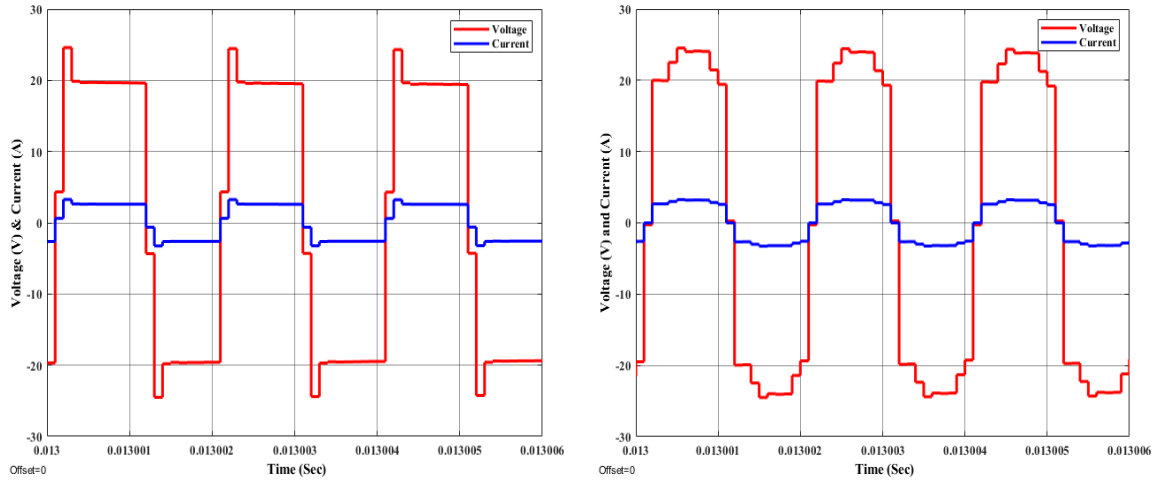
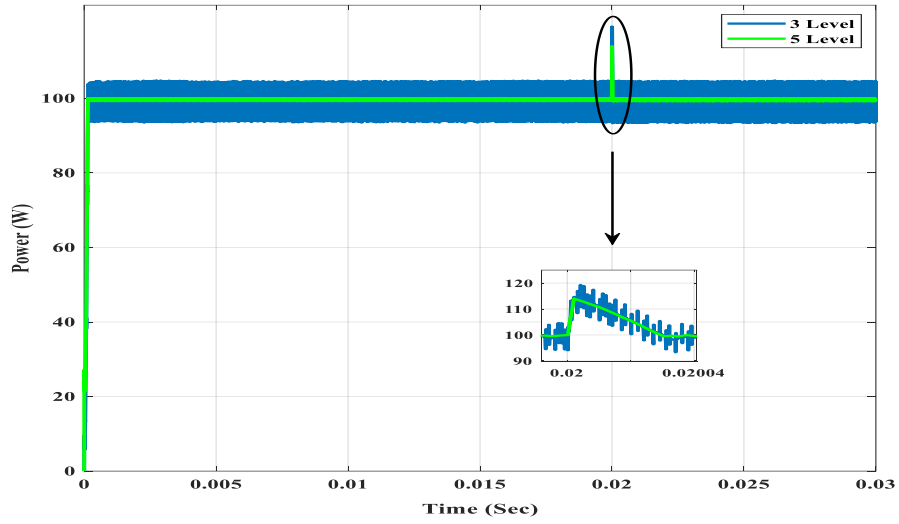
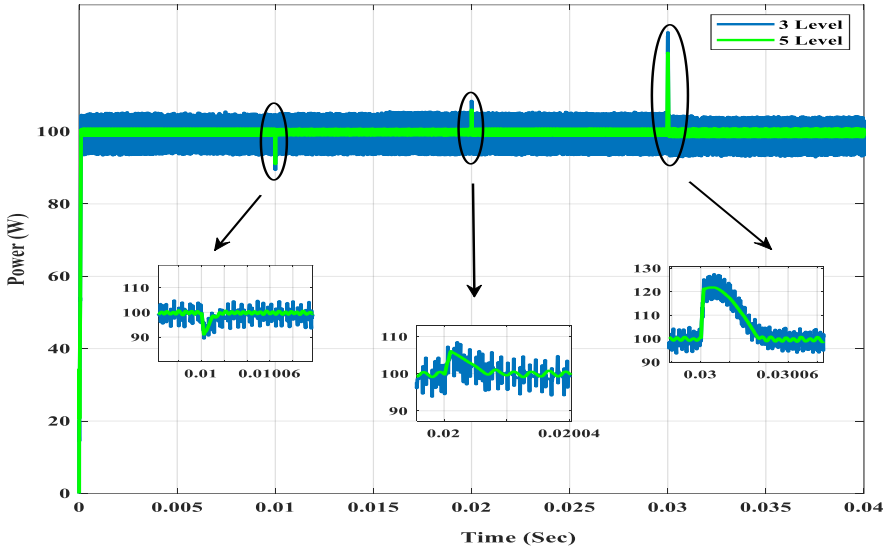


Figure 6. Output voltage and output current in 3 and 5 Level inverter circuit. *Source: Authors.*

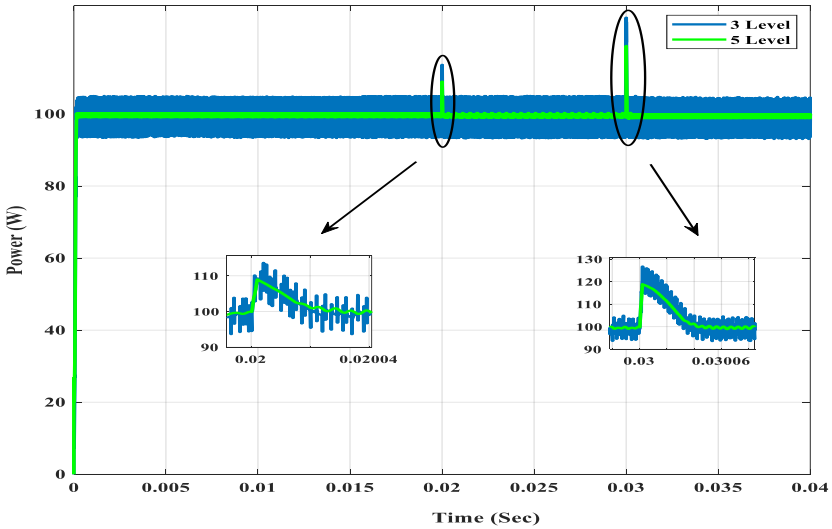
In the case of employing PSO for tuning the parameters of FO-PID controller, Figure 7 illustrates the response of the output power of the ESG with traditional inverter circuit and the advanced 5 multilevel inverter circuit for the three load models. Tables 1, 2 and 3 show the comparison of the performance characteristics for the ESG, where Lxy represents type of layers (x: type for modes and y: type for layers). Four modes of control are used, considering overshot (OS (%)), and the percentage of reduction heat (↓RH (%)) for child, male, and female tissues. Additionally, two different types of inverters were used, including a conventional inverter and five multilayer inverters. Additionally, when a multilevel inverter is employed, the magnitude of overshot is reduced relative to when a traditional inverter is used. Furthermore, when compared to optimal IO-PID controllers, employing optimal FO-PID controller parameters in ESG can improve performance and decrease heat generation.



Child



Male



Female

Figure 7. Output power in 3 and 5 Level invert circuit for FO-PSO-PID of ESG. *Source: Authors.*

Table 1. Performance characteristics of ESG for case study child tissues. *Source: Authors.*

Tissue Layer	Performance Factors	Symbol	PID Controller			
			IO	IO-PSO	FO	FO-PSO
L_{11}	3-Level Inverter					
	Overshoot	OS (%)	19.62	10.50	5.09	4.28
	Settling Time	Ts (μs)	18.13	17.86	17.68	17.14
	THD of current	THD_i (%)	41.36	41.36	41.34	41.34
	Reduction Heat	RH (%)	0	8.99	14.34	17.57
	5-Level Inverter					
	Overshoot	OS (%)	12.13	3.91	0.43	0.04
	Settling Time	Ts (μs)	14.58	13.75	13.21	12.67
	THD of current	THD_i (%)	21.69	21.69	21.67	21.67
	Reduction Heat	RH (%)	24.63	34.13	99.73	99.97
L_{12}	3-Level Inverter					
	Overshoot	OS (%)	5.55	5.14	4.56	4.45
	Settling Time	Ts (μs)	12.86	12.83	12.06	12.03
	THD of current	THD_i (%)	41.36	41.36	41.34	41.34
	Reduction Heat	RH (%)	0	0.66	7.14	7.45
	5-Level Inverter					
	Overshoot	OS (%)	0.89	0.82	0.17	0.02
	Settling Time	Ts (μs)	11.97	11.86	11.59	11.45
	THD of current	THD_i (%)	21.69	21.69	21.67	21.67
	Reduction Heat	RH (%)	99.21	99.28	99.85	99.98
L_{13}	3-Level Inverter					
	Overshoot	OS (%)	26.69	25.03	23.24	19.47
	Settling Time	Ts (μs)	40.88	40.57	40.23	40.22
	THD of current	THD_i (%)	41.36	41.36	41.34	41.34
	Reduction Heat	RH (%)	0	2.06	4.28	8.94
	5-Level Inverter					
	Overshoot	OS (%)	21.54	21.38	19.96	13.98
	Settling Time	Ts (μs)	24.87	24.81	24.21	23.97
	THD of current	THD_i (%)	21.69	21.69	21.67	21.67
	Reduction Heat	RH (%)	41.64	41.86	43.92	47.28

Impact of ESG

The power-controlled power of ESG units can have several positive impacts on surgical procedures, including:

- The ability to control the power output of electrosurgical devices, which allows surgeons to achieve more precise tissue cutting and coagulation, resulting in less tissue damage and a quicker healing time for the patient.
- By controlling the power of ESG units, surgeons can minimize the risk of unintended injuries or complications, such as burns, tissue damage, and hemorrhage.
- The precise cutting and coagulation capabilities of electrosurgical devices can reduce the time of surgery and operation, which leads to faster patient recovery and reduced healthcare costs.
- Controlled power of ESG units can reduce blood loss during surgery, which can be particularly important in procedures where blood loss is a concern.
- By minimizing the risk of unintended injuries and complications, controlled power of ESG units can enhance the safety of surgical procedures for both the patient and the surgical team.

Table 2. Performance characteristics of ESG for case study male tissues. *Source: Authors*

Tissue Layer	**Performance Factors**	**Symbol**	**PID Controller**			
			IO	**IO-PSO**	**FO**	**FO-PSO**
L_{21}	3-Level Inverter					
	Overshoot	OS (%)	8.31	5.26	5.22	4.67
	Settling Time	Ts (µs)	13.03	12.83	12.48	12.20
	THD of current	THD_i (%)	41.53	41.53	41.52	41.52
	Reduction Heat	RH (%)	0	4.32	6.94	9.56
	5-Level Inverter					
	Overshoot	OS (%)	4.50	2.42	0.71	0.62
	Settling Time	Ts (µs)	11.87	11.26	10.96	10.01
	THD of current	THD_i (%)	18.84	18.84	18.84	18.84
	Reduction Heat	RH (%)	12.11	18.28	99.45	99.56
L_{22}	3-Level Inverter					
	Overshoot	OS (%)	7.09	4.69	4.35	4.00
	Settling Time	Ts (µs)	25.73	25.49	25.17	25.03
	THD of current	THD_i (%)	41.53	41.53	41.52	41.52
	Reduction Heat	RH (%)	0	3.15	4.68	5.51
	5-Level Inverter					
	Overshoot	OS (%)	2.09	1.39	0.73	0.64
	Settling Time	Ts (µs)	17.53	17.46	16.76	16.21
	THD of current	THD_i (%)	18.84	18.84	18.84	18.84
	Reduction Heat	RH (%)	35.06	35.78	99.55	99.62
L_{23}	3-Level Inverter					
	Overshoot	OS (%)	17.35	15.31	13.92	9.87
	Settling Time	Ts (µs)	31.16	30.71	30.64	30.31
	THD of current	THD_i (%)	41.53	41.53	41.52	41.52
	Reduction Heat	RH (%)	0	3.14	4.54	8.91
	5-Level Inverter					
	Overshoot	OS (%)	10.87	10.34	8.37	6.04
	Settling Time	Ts (µs)	26.11	25.77	25.71	25.48
	THD of current	THD_i (%)	18.84	18.84	18.84	18.84
	Reduction Heat	RH (%)	20.84	22.23	23.79	26.12
L_{24}	3-Level Inverter					
	Overshoot	OS (%)	40.12	36.03	34.94	28.76
	Settling Time	Ts (µs)	61.23	60.97	60.86	60.45
	THD of current	THD_i (%)	41.53	41.53	41.52	41.52
	Reduction Heat	RH (%)	0	3.63	4.27	9.27
	5-Level Inverter					
	Overshoot	OS (%)	30.50	30.46	29.79	21.75
	Settling Time	Ts (µs)	47.01	46.86	46.12	45.97
	THD of current	THD_i (%)	18.84	18.84	18.84	18.84
	Reduction Heat	RH (%)	28.49	28.74	30.23	34.77

Table 3. Performance characteristics of ESG for case study female tissues. *Source: Authors.*

Tissue Layer	Performance Factors	Symbol	PID Controller			
			IO	IO-PSO	FO	FO-PSO
L_{31}	3-Level Inverter					
	Overshoot	OS (%)	16.03	5.69	5.11	4.62
	Settling Time	Ts (µs)	16.03	15.66	15.62	15.49
	THD of current	THD_i (%)	40.79	40.79	40.78	40.78
	Reduction Heat	RH (%)	0	10.97	11.72	12.85
	5-Level Inverter					
	Overshoot	OS (%)	9.12	5.02	0.45	0.11
	Settling Time	Ts (µs)	14.45	14.15	13.65	12.59
	THD of current	THD_i (%)	18.55	18.55	18.55	18.55
	Reduction Heat	RH (%)	15.22	20.06	99.66	99.92
L_{32}	3-Level Inverter					
	Overshoot	OS (%)	8.57	6.72	6.65	4.58
	Settling Time	Ts (µs)	15.86	15.46	15.21	15.11
	THD of current	THD_i (%)	40.79	40.79	40.78	40.78
	Reduction Heat	RH (%)	0	4.18	5.75	8.19
	5-Level Inverter					
	Overshoot	OS (%)	2.90	2.18	1.53	0.29
	Settling Time	Ts (µs)	11.84	11.54	10.73	10.34
	THD of current	THD_i (%)	18.55	18.55	18.55	18.55
	Reduction Heat	RH (%)	29.22	31.49	36.72	99.82
L_{33}	3-Level Inverter					
	Overshoot	OS (%)	20.16	18.55	16.92	13.73
	Settling Time	Ts (µs)	40.91	40.48	40.37	40.25
	THD of current	THD_i (%)	40.79	40.79	40.78	40.78
	Reduction Heat	RH (%)	0	2.38	3.96	6.87
	5-Level Inverter					
	Overshoot	OS (%)	13.78	13.34	12.62	8.96
	Settling Time	Ts (µs)	28.33	27.04	26.48	25.50
	THD of current	THD_i (%)	18.55	18.55	18.55	18.55
	Reduction Heat	RH (%)	34.48	37.66	39.32	43.47
L_{34}	3-Level Inverter					
	Overshoot	OS (%)	33.29	32.33	31.47	26.74
	Settling Time	Ts (µs)	50.97	50.89	50.86	50.45
	THD of current	THD_i (%)	40.79	40.79	40.78	40.78
	Reduction Heat	RH (%)	0	0.86	1.57	5.87
	5-Level Inverter					
	Overshoot	OS (%)	26.50	26.09	25.02	18.87
	Settling Time	Ts (µs)	46.45	45.94	45.18	40.33
	THD of current	THD_i (%)	18.55	18.55	18.55	18.55
	Reduction Heat	RH (%)	13.51	14.73	16.85	29.93

Conclusions

The conclusion of the research can be summarized as follows. A comprehensive study on power adjusting and heat dissipation in ESG units is demonstrated. The approach involved is implementing IO-PID and FO-PID controllers and optimizing their parameters using the conventional PSO algorithm. The typical H-bridge inverter is modified with an advanced five-level MLI to reduce heat dissipation and improve THD. The simulation results demonstrate that the FO-PID controller outperforms the IO-PID controller, especially when optimized using the PSO algorithm. This improvement is evident in the reduced overshot and settling times of the output power, as well as the significant decrease in heat dissipation. Moreover, the advanced five-level MLI is found to be more practical and efficient in reducing heat generation and THD compared to the typical H-bridge inverter.

The findings of this study have important implications for the design of ESG devices, which provide an effective method to mitigate the drawbacks of output power and heat dissipation. The optimal combination of FO-PID controller parameters and the advanced five-level MLI can be applied to other electrosurgical devices to achieve

better control of output power and heat dissipation. Future research will focus on developing an accurate thermal model of tissue to better understand the thermal behavior of tissue during surgery. The proposed heat equivalent circuit, as achieved in [32], will be used to demonstrate the heat transfer mechanisms between the tissue and ESG, providing insights into optimizing the performance of ESGs while maintaining patient safety.

Conflict of interest

The authors declare no conflict of interest.

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MANAGING OF RESPONSIBLE CONSUMPTION AND SUSTAINABLE PRODUCTION OF ENTERPRISES IN THE GLOCALIZATION CONDITIONS

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Highlight
Consumption and sustainable production enterprises in the glocalization conditions.

Abstract
The article discusses principal issues related to lean production and consumption, providing the author's perspective on the factors and initiatives necessary for their implementation. The paper emphasizes the importance of each stakeholder's role in sustainable development. The agricultural market is analyzed, and general steps for implementing a Sustainable Development Strategy are proposed, including simulations of sales and pricing policies after the introduction of sustainable development aspects. With the world's population growing and resources declining, there is a need to meet increasing demand while also conserving water resources, agricultural land, and promoting environmentally friendly labour practices. To achieve this, countries must adopt innovative approaches to responsible consumption and sustainable production, particularly considering the socio-economic impact of COVID-19. Therefore, it is essential to develop an innovative model of sustainable consumption and production. COVID-19 has become a catalyst for socio-economic change, highlighting the adaptability of countries to change and the necessity for effective restoration and implementation of sustainable production and consumption models. This article explores the management of responsible consumption and sustainable production enterprises in the context of glocalization. It analyses the impact of global trends and local contexts on businesses striving for sustainable development. The article emphasizes the role of leadership, strategic planning, and the implementation of effective management practices

in achieving these goals. The authors examine various models and approaches to managing responsible consumption and sustainable production, including concepts of green manufacturing, circular economy, and corporate social responsibility. They consider advanced practices and initiatives in these areas that are already successfully implemented by large and small enterprises. The article also investigates the influence of glocalization on enterprise management. Glocalization is defined as the convergence of global and local factors influencing businesses. It highlights the need for enterprises to adapt their strategies and operations to the specific cultural, social, and environmental contexts in which they operate, while also addressing global challenges related to responsible consumption and sustainable production.

Keywords
managing innovative development; responsible consumption; sustainable production; decoupling factor.

Introduction

Today, there are almost 700 million people starving while about one-third of the world's products are wasted due to various reasons. If production continues to increase, it will have a negative impact on the environment, leading to the depletion of soil, water, and nutrients, greenhouse gas emissions, and ecosystem degradation. This situation is unacceptable for socio-economic development and will have a growing negative effect. The Food and Agriculture Organization (FAO) requests the separation of resources from their impact on sustainable consumption and production patterns to transition to a greener and socially inclusive global economy. Sustainable practices will lead to the "respect" of biophysical borders and reduce global consumption to meet the biophysical potential of ecosystem services. Responsible consumption and sustainable production should be mainstreamed to mitigate the socio-economic impact of COVID-19. The pandemic, financial crisis, and war provide an opportunity to rethink the social, economic, and political state of the world economy. Relevant trends encourage a systemic transition to a sustainable economy that will benefit humanity and the planet.

The axiom of modernity is that the needs of people are unlimited, but the planet's ability to meet them is limited. Scientists are trying to understand and assess the limits of human use of natural resources before causing irreversible negative impacts. The borders should be delineated and updated at the state level to avoid economic and societal destruction [1,2]. The key task is to increase environmental friendliness to avoid the formation of "climate stress." An opportunity for resource-intensive enterprises is the "development of new markets for climate-neutral and cyclical products”. Industrial activity causes 90% of biodiversity loss and water degradation and 20% of total emissions in the European Union, while only 12% of recycled materials are used. The corresponding strategy aims to modernize resource-intensive production and stimulate recycling and reuse of products with state support. The European Green Deal is an ambitious growth strategy launched at the EU level in response to environmental degradation and recent climate change. The corresponding strategy aims to reduce harmful impacts on the environment and ensure a future with "zero pollution, affordable and safe energy, smarter transport, and high-quality food." Almost one trillion euros will be allocated to measures aimed at all economic sectors focused on clean technologies, innovation, cheaper and greener transport, a decarbonized energy sector, and efficient buildings. Small and medium-sized enterprises (SMEs) are considered fundamental to the European economy, providing more than 50% of Europe's GDP and approximately 70% of all jobs.

However, going digital or green is a more complex process for SMEs than for larger companies. The topic of managing responsible consumption and sustainable production enterprises in glocalization conditions is of utmost importance and relevance in today's globalized world. Glocalization, which refers to the fusion of global and local factors, has significant implications for businesses seeking to achieve sustainability goals. Managing responsible consumption involves promoting environmentally conscious behaviors among consumers and encouraging them to make sustainable choices. This includes reducing waste, minimizing carbon footprints, and supporting eco-friendly products and services. Sustainable production, on the other hand, focuses on implementing practices that minimize environmental impact throughout the production process, such as resource efficiency, renewable energy usage, and waste reduction. In glocalization conditions, businesses face the challenge of balancing global trends and local contexts. They must adapt their strategies and operations to meet the specific needs and preferences of local markets while also addressing global sustainability challenges. This requires a comprehensive understanding of the socio-cultural, economic, and environmental factors influencing consumer behavior and production practices. By effectively managing responsible consumption and sustainable production enterprises in glocalization conditions, businesses can contribute to the achievement of global sustainability goals. They can minimize their ecological footprint, conserve

resources, and contribute to the well-being of local communities. Additionally, such enterprises can enhance their reputation, attract environmentally conscious consumers, and gain a competitive advantage in the marketplace.

Overall, the topic of managing responsible consumption and sustainable production enterprises in glocalization conditions is crucial in creating a more sustainable and environmentally conscious business environment that addresses both local and global sustainability challenges. For example, some interesting practical case studies that demonstrate the management of responsible consumption and sustainable production in the context of glocalization:

- Interface: Interface, a global carpet manufacturer, implemented a sustainability strategy called "Mission Zero" with the goal of eliminating any negative impact on the environment by 2020. They focused on reducing waste, using renewable energy sources, and promoting responsible sourcing of materials. Through their innovative approach, they successfully transformed their production processes and became a leader in sustainable business practices.
- Unilever: Unilever, a multinational consumer goods company, has embraced responsible consumption and sustainable production through its Sustainable Living Plan. They have set ambitious targets to reduce the environmental footprint of their products, promote social responsibility, and improve the health and well-being of their consumers. Unilever's initiatives include sustainable sourcing of raw materials, packaging innovations, and educating consumers about sustainable choices.
- Tesla: Tesla, an electric vehicle manufacturer, has revolutionized the automotive industry by promoting sustainable transportation. Their electric cars offer an alternative to traditional fossil fuel-powered vehicles, reducing greenhouse gas emissions and dependence on non-renewable energy sources. Tesla's commitment to sustainable production extends beyond their products to their Gigafactories, which aim to operate on renewable energy and minimize environmental impact.
- The Body Shop: The Body Shop, a cosmetics and skincare company, has long been committed to ethical sourcing and responsible production. They actively promote fair trade practices, sustainable packaging, and community empowerment. The Body Shop sources natural ingredients from around the world, ensuring that local communities benefit from their activities while minimizing environmental harm.

These case studies demonstrate successful initiatives in managing responsible consumption and sustainable production in the glocalization conditions, highlighting how companies can integrate environmental and social considerations into their business strategies for long-term success. While managing responsible consumption and sustainable production enterprises in the glocalization conditions brings numerous positive outcomes, there are also some negative aspects to consider. Here are a few:

- Greenwashing: Some companies may engage in greenwashing, which involves presenting a misleading or exaggerated image of environmental responsibility. They may claim to be sustainable or eco-friendly without implementing substantial changes in their practices. This can mislead consumers and undermine the credibility of genuine sustainability efforts.
- Lack of standardization: The absence of standardized regulations and definitions for responsible consumption and sustainable production can create challenges. Different countries and regions may have varying interpretations and criteria, making it difficult to compare and assess the environmental and social impact of different enterprises accurately.
- Supply chain complexities: Achieving sustainable production requires collaboration and coordination across complex global supply chains. Ensuring responsible sourcing of materials, minimizing waste, and monitoring environmental and social practices throughout the supply chain can be challenging. Lack of transparency and traceability can hinder efforts to achieve sustainability goals.
- Affordability and accessibility: Responsible consumption products and sustainable alternatives may sometimes be more expensive or less accessible to certain segments of the population. This can create inequalities in access to sustainable options and limit the widespread adoption of responsible consumption practices.
- Balancing economic growth and sustainability: Achieving sustainable production and consumption while maintaining economic growth can be a delicate balance. Some enterprises may prioritize short-term profitability over long-term sustainability goals, leading to conflicts between economic interests and environmental/social considerations.

It is crucial for stakeholders to address these negative aspects and work towards overcoming challenges to ensure the genuine implementation of responsible consumption and sustainable production

in glocalization conditions.

Methods

The paper discusses the important topic of how small and medium-sized enterprises (SMEs) can contribute to sustainable and inclusive growth through the provision of green jobs. However, in many developing countries, these companies struggle with the cost of innovation and technology transfer, making government support programs crucial. Methods for managing responsible consumption and sustainable production enterprises in glocalization conditions involve a range of strategies and approaches. Here are some key methods that can be employed:

- Stakeholder Engagement: Engaging and involving various stakeholders such as consumers, employees, suppliers, local communities, and governmental organizations is crucial. This can be done through communication, collaboration, and incorporating their perspectives and feedback into decision-making processes.
- Sustainable Supply Chain Management: Implementing sustainable practices throughout the supply chain, including sourcing raw materials responsibly, promoting fair trade, reducing waste, and optimizing logistics, can contribute to responsible consumption and sustainable production.
- Life Cycle Assessment: Conducting life cycle assessments to evaluate the environmental impacts of products or services from production to disposal. This helps identify areas for improvement and informs decision-making regarding resource usage, product design, and waste management.
- Circular Economy Principles: Adopting circular economy principles, such as designing products for reuse, recycling, or refurbishment, can minimize waste and promote a more sustainable production and consumption cycle.
- Green Technologies and Innovation: Embracing and implementing green technologies and innovation can enhance resource efficiency, reduce emissions, and improve overall sustainability performance. This includes adopting renewable energy sources, implementing energy-saving measures, and exploring sustainable packaging solutions.
- Education and Awareness: Promoting education and awareness initiatives to increase consumer knowledge about responsible consumption and sustainable production practices. This can be achieved through marketing campaigns, consumer education programs, and partnerships with educational institutions or NGOs.
- Regulatory Compliance: Adhering to and complying with relevant environmental regulations and standards is essential for managing responsible consumption and sustainable production. This includes monitoring and reporting on environmental performance and ensuring compliance with legal requirements.
- Collaboration and Partnerships: Collaborating with other businesses, industry associations, NGOs, and government entities can foster knowledge sharing, best practice exchange, and collective efforts to address sustainability challenges and promote responsible consumption and sustainable production.

These methods, when implemented collectively and tailored to specific glocalization conditions, can contribute to the effective management of responsible consumption and sustainable production enterprises. They help businesses align their operations with global sustainability goals while considering the unique local contexts in which they operate. Quantitative evaluation methods can be used to measure the effectiveness of managing responsible consumption and sustainable production in the context of globalization. Some of these methods include:

- Life cycle assessment (LCA) - a method of assessing the environmental impact of a product at all stages of its life cycle, from raw material extraction to disposal. It can be used to evaluate the sustainability of production.
- Key performance indicators (KPIs) - metrics used to assess the effectiveness of managing responsible consumption and sustainable production, such as energy consumption, atmospheric emissions, and water use. They can be used to compare the performance of companies in the industry.
- Corporate social responsibility (CSR) assessment - a method used to measure a company's level of social responsibility towards its employees, customers, community, and the environment. It can be used to evaluate the effectiveness of managing responsible consumption and sustainable production.
- Certification systems - standards and certification programs that establish sustainability criteria for products and services. They can help companies achieve high sustainability standards and increase

consumer and stakeholder trust.

- Impact assessment - a method used to measure a company's impact on the environment and society, including its impact on climate, human health, and well-being. It can be used to evaluate the effectiveness of managing responsible consumption and sustainable production.

These methods can be used to measure the effectiveness of managing responsible consumption and sustainable production in the context of globalization. The study of eco-enterprises is relevant globally, but not all countries are currently engaged in the analysis of green entrepreneurship, despite its importance for economic and social development. Therefore, it is important to debunk the myth that eco-entrepreneurship is expensive and negatively affects profitability. Finally, it is crucial to develop a comprehensive economic and political approach that harmonizes the impact of management decisions across different states.

Here is one possible mathematical model for the relationship between responsible consumption and sustainable production enterprises in glocalization conditions:

$$(1) \qquad Y = f(X1, X2, X3, X4, X5, X6, X7)$$

where:
Y = Performance of enterprises in responsible consumption and sustainable production practices
X1 = Adoption of sustainable production practices
X2 = Adoption of responsible consumption practices
X3 = Ability to adapt to changing market conditions
X4 = Meeting demands of customers and stakeholders
X5 = Enhancing reputation and competitive advantage
X6 = Contributing to global sustainable development goals
X7 = Leveraging opportunities presented by new technologies and digitalization

The function f represents the relationship between these variables and the performance of enterprises in responsible consumption and sustainable production practices. The model suggests that the adoption of sustainable production and responsible consumption practices, along with the ability to adapt to changing market conditions, meet customer and stakeholder demands, enhance reputation and competitive advantage, and contribute to global sustainable development goals, all contribute to the performance of enterprises in this area. Leveraging opportunities presented by new technologies and digitalization is also likely to have an appositive impact on performance.

Facts and Implications of Lean Production and Consumption:

- Waste Reduction: Lean production focuses on minimizing waste across all aspects of the production process. By identifying and eliminating non-value-added activities, companies can reduce costs, improve efficiency, and enhance overall productivity.
- Efficiency and Quality Improvement: Lean production emphasizes continuous improvement and streamlining operations. This approach leads to increased efficiency, shorter production cycles, and improved product quality. By eliminating waste and optimizing processes, companies can deliver products and services that meet or exceed customer expectations.
- Supply Chain Optimization: Lean production extends beyond the boundaries of individual companies and includes the entire supply chain. It emphasizes collaboration, coordination, and synchronization among suppliers, manufacturers, and distributors. This helps reduce inventory levels, minimize lead times, and improve overall supply chain performance.
- Employee Empowerment and Engagement: Lean production encourages employee involvement and empowerment. It promotes a culture of continuous improvement, where employees are encouraged to identify and address inefficiencies. This leads to increased engagement, motivation, and innovation among employees, fostering a positive work environment.
- Environmental Benefits: Lean production inherently promotes environmental sustainability by reducing waste, energy consumption, and emissions. By minimizing overproduction, transportation, and unnecessary inventory, companies can minimize their ecological footprint and contribute to a more sustainable future.
- Customer Focus: Lean production places a strong emphasis on understanding and meeting customer needs. By eliminating waste and delivering products and services efficiently, companies can improve

- customer satisfaction and loyalty. This customer-centric approach drives competitiveness and long-term success.

The implications of adopting lean production and consumption practices include improved financial performance, enhanced competitiveness, reduced environmental impact, increased customer satisfaction, and a more engaged workforce. By embracing lean principles, companies can achieve sustainable growth and contribute to a more efficient and responsible economy.

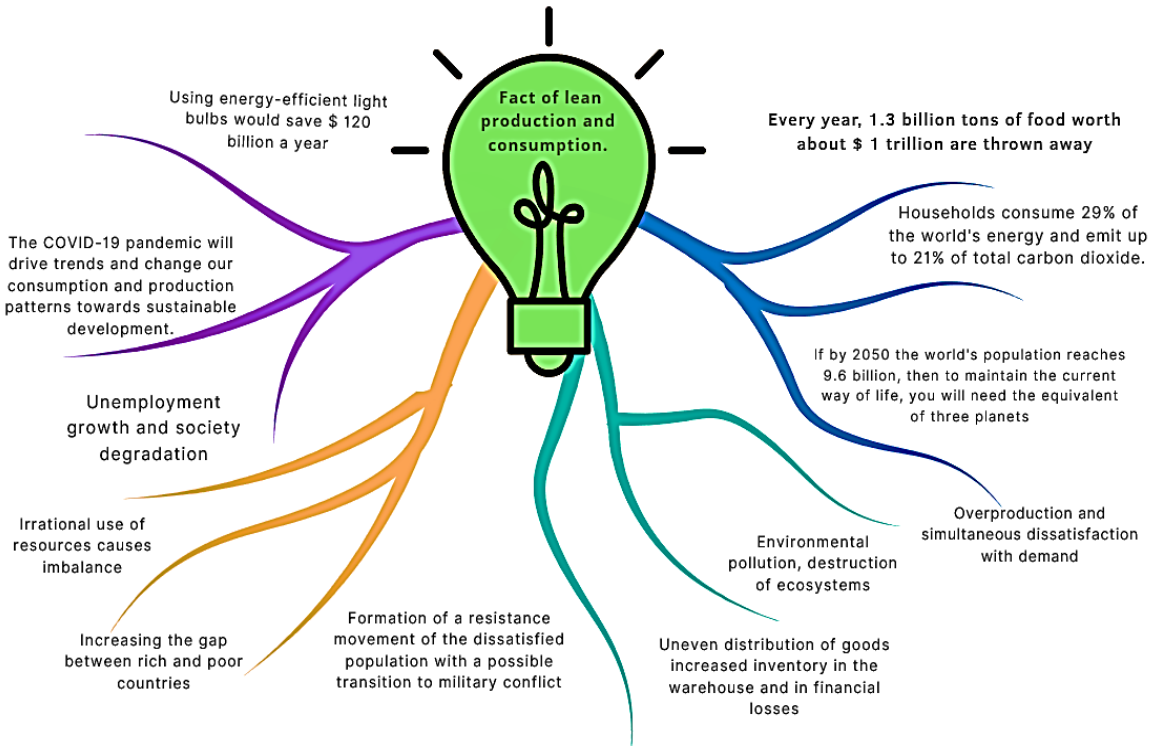


Figure 1. Facts and implications of lean production and consumption. *Source: Author.*

During our study, we came to the appropriate to distribute responsible consumption by sectors Figure 2. Lean production and consumption are an approach to manufacturing and consumption that emphasizes efficiency and waste reduction. Some key facts and implications of this approach include:

- Focus on reducing waste: Lean production and consumption is focused on reducing waste in all forms, including time, energy, materials, and labor. This can lead to significant cost savings and environmental benefits.
- Continuous improvement: Lean production and consumption involves an ongoing process of identifying and eliminating waste through continuous improvement. This requires a culture of innovation and flexibility within an organization.
- Improved quality: By reducing waste and streamlining processes, lean production and consumption can lead to improved product quality and customer satisfaction.
- Increased productivity: Lean production and consumption can increase productivity by reducing downtime, improving efficiency, and increasing employee engagement.
- Sustainable development: Lean production and consumption can contribute to sustainable development by reducing environmental impact, conserving resources, and promoting social equity.
- Challenges: Implementing lean production and consumption can be challenging, as it requires significant changes in organizational culture, management practices, and supply chain relationships. Additionally, there can be resistance from employees and stakeholders who may be skeptical of the benefits of lean production and consumption.

Overall, lean production and consumption can lead to significant benefits for organizations, the environment, and society. However, it requires a commitment to continuous improvement and a willingness to embrace change. Mostly, companies instead of conducting a supply and demand analysis, simply reduce the goods

produced number that are correlated with price increases. But instead of adapting businesses to modern demands of sustainable development and raising awareness of the need for frugal consumption, we have the opposite effect, which mostly encourages consumers to buy more to make stocks [3,4].

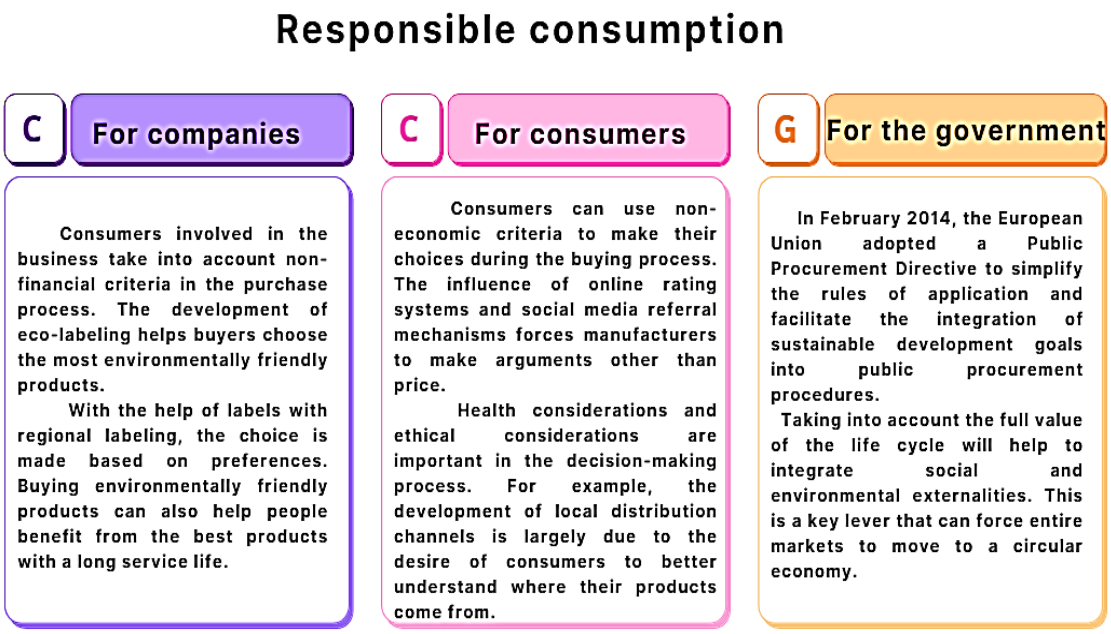
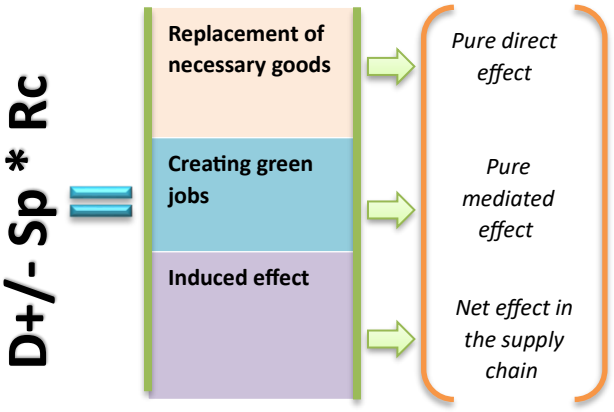


Figure 2. Responsible consumption sectoral distribution of influence on consumer preferences. *Source: Author.*

For successful interaction of production and consumption it is expedient to use the set algorithm Figure 3.



D- Demand, Sp - Sustainable production, Rc - Responsible consumption

Figure 3. Formula impact Responsible consumption and Sustainable production. *Source: Author.*

And this trend is again launching sweeping overproduction and an increase in unsold products. That is, the concept of sustainable consumption and production is to do more and better than less resource costs. It is also about separating economic growth from environmental degradation to resource efficiency and sustainable living. Sustainable consumption and production can make a significant contribution to overcoming poverty and the transition to a low-carbon and green economy. The formula impact of responsible consumption and sustainable production can be expressed as follows:

Impact = Environmental Benefits + Social Benefits + Economic Benefits

Environmental Benefits: Responsible consumption and sustainable production practices aim to minimize the negative environmental impacts of industrial activities. This includes reducing carbon emissions, conserving

natural resources, protecting ecosystems, and minimizing pollution. The environmental benefits can be measured in terms of reduced greenhouse gas emissions, improved air and water quality, preserved biodiversity, and reduced waste generation.

Social Benefits: Responsible consumption and sustainable production also have positive social impacts. This includes improving working conditions, promoting fair trade and ethical practices, supporting local communities, and enhancing social equity. The social benefits can be measured in terms of improved livelihoods, reduced inequality, increased community engagement, and enhanced well-being of stakeholders.

Economic Benefits: Responsible consumption and sustainable production can lead to economic benefits for businesses and societies. This includes cost savings through resource efficiency, reduced operational expenses, improved productivity, and access to new markets. Additionally, the growing demand for sustainable products and services presents economic opportunities for businesses that embrace sustainability. The economic benefits can be measured in terms of increased profitability, market competitiveness, job creation, and long - term economic resilience.

By considering the environmental, social, and economic dimensions, the impact of responsible consumption and sustainable production can be assessed comprehensively. This formula helps to quantify and evaluate the overall positive outcomes and contributions of these practices to a more sustainable future.

Results and discussion

Glocalization is a concept that recognizes the interconnectedness between global and local factors. It acknowledges that businesses and organizations must consider both global trends and local contexts when developing and implementing strategies related to responsible consumption and sustainable production. Glocalization emphasizes the adaptation of global ideas and practices to meet local needs and preferences. In this context, managing responsible consumption involves promoting and encouraging consumers to make informed choices that prioritize sustainability and minimize negative environmental and social impacts. It involves raising awareness, providing information, and offering sustainable alternatives to consumers. This may include initiatives such as promoting eco-friendly products, encouraging recycling and waste reduction, and advocating for ethical sourcing practices. On the other hand, managing sustainable production entails implementing practices that minimize the environmental footprint of production processes while ensuring the well-being of workers and communities. It involves integrating sustainability principles throughout the entire production cycle, including resource efficiency, waste reduction, renewable energy adoption, and fair labour practices. Sustainable production aims to minimize negative impacts on the environment and society while maintaining economic viability. Managing responsible consumption and sustainable production in glocalization conditions requires considering the unique characteristics and challenges of both global and local contexts. It involves understanding cultural, economic, regulatory, and societal factors that influence consumption patterns and production practices in different regions. This may involve adapting strategies to align with local values, addressing specific challenges in supply chains, collaborating with local stakeholders, and adhering to relevant regulations and standards.

Overall, managing responsible consumption and sustainable production enterprises in glocalization conditions involves adopting a holistic and integrated approach that considers both global sustainability goals and local realities. It seeks to balance economic growth, environmental preservation, and social well-being, recognizing that sustainable practices are essential for long-term business success and the well-being of the planet and its inhabitants. Ensuring sustainable development for agribusiness in Ukraine is the number one priority. However, it is worth noting. The paper highlights that while certain measures may have a positive impact on the industry, they can also have negative consequences in other areas. For instance, there may be trade-offs between facilitating small farmers' access to resources and improving soil quality and land reclamation [5,6].

As a result, the threshold of environmental security will become increasingly important in the agricultural sector of Ukraine soon, and scaling solutions at every stage of the supply chain will be necessary, particularly where quick results can be achieved. Although this is a challenging task, the consequences of inaction are already being felt downstream, with around 58% of EU companies reporting that their activities are currently being affected by weather conditions, and inaction could worsen the situation [7,8]. Therefore, building knowledge and developing the capacity of producers through the implementation of approaches that increase resilience to external factors can reduce losses, promote reuse and recycling, and support sustainable consumption.

Our research on managing responsible consumption and sustainable production enterprises in the context of glocalization stands out due to its unique contributions and approach. Here are the key aspects that make our study distinctive:

- Comprehensive Analysis: Our research provides a comprehensive analysis of the challenges and opportunities related to responsible consumption and sustainable production in glocalization conditions. We delve into various dimensions, including economic, environmental, and social aspects, to offer a holistic understanding of the topic.
- Glocalization Perspective: We specifically focus on the glocalization context, which refers to the interconnectedness of global and local factors. By exploring how responsible consumption and sustainable production practices adapt to glocalization conditions, we shed light on the dynamics between global trends and local requirements.
- Stakeholder Perspectives: Our study emphasizes the importance of stakeholder engagement in sustainable development. We examine the roles and responsibilities of various stakeholders, such as businesses, governments, and consumers, in driving responsible consumption and sustainable production. This multi-dimensional analysis adds depth to our research.
- Innovative Strategies: We propose innovative strategies and approaches for managing responsible consumption and sustainable production in glocalization conditions. Our research goes beyond theoretical frameworks by providing practical insights, recommendations, and simulations of potential outcomes.
- Relevance in the Current Context: Our study acknowledges the socio-economic impact of significant events such as the COVID-19 pandemic. We discuss the implications of these events on responsible consumption and sustainable production, highlighting the need for adaptive strategies and effective restoration in a rapidly changing world.
- Potential for Real-World Impact: Our research aims to bridge the gap between theory and practice by offering actionable insights for enterprises and policymakers. We believe that our findings have the potential to influence decision-making processes and inspire innovative solutions that promote responsible consumption and sustainable production.

In summary, our research on managing responsible consumption and sustainable production enterprises in glocalization conditions stands out for its comprehensive analysis, glocalization perspective, stakeholder engagement, innovative strategies, relevance, and potential for real-world impact. By addressing these unique aspects, we contribute to the existing body of knowledge and provide valuable guidance for businesses, policymakers, and other stakeholders in fostering sustainable development. To analyse the sustainable development of agricultural enterprises, it is advisable to use our proposed algorithm, which in the future will not only assess the business, but also allow to form further goals to improve their functioning Figure 4.

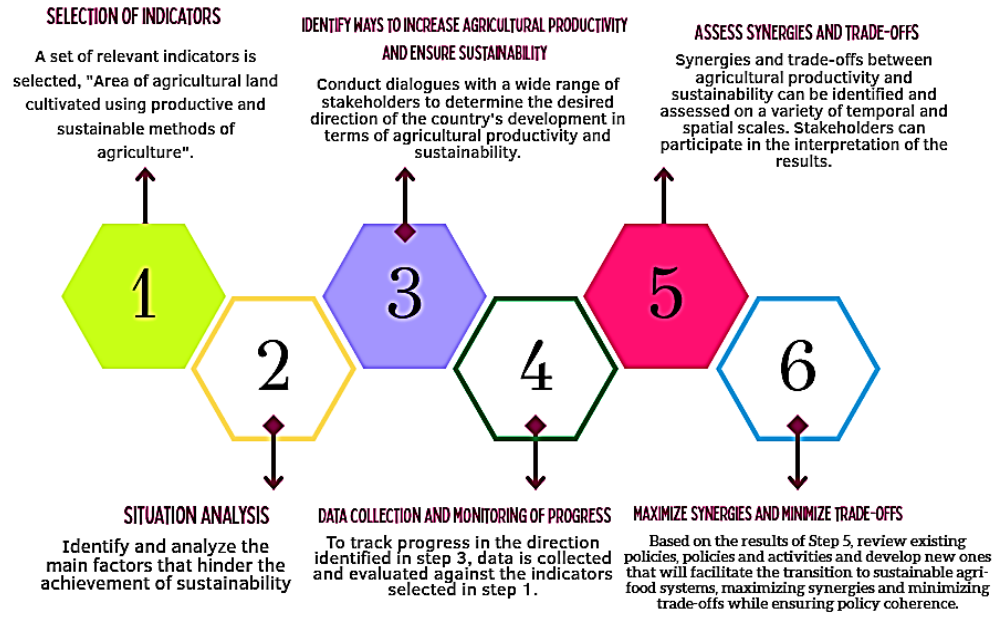


Figure 4. Steps to assess the compliance of agribusiness to the conditions of sustainable production. *Source: Author.*

Assessing the compliance of agribusiness to the conditions of sustainable production involves several steps. Here are some key steps to consider:

- Define Sustainable Production Criteria: Begin by defining the criteria and standards for sustainable production in the context of agribusiness. This may include environmental considerations such as resource conservation, biodiversity preservation, and reduced chemical use, as well as social aspects such as fair labour practices, community engagement, and ethical sourcing.
- Conduct a Gap Analysis: Evaluate the current practices and operations of the agribusiness against the defined sustainable production criteria. Identify areas where the business falls short and identify the gaps that need to be addressed to achieve compliance.
- Assess Environmental Impact: Evaluate the environmental impact of the agribusiness operations. This may involve assessing factors such as greenhouse gas emissions, water and energy consumption, waste generation, and pollution levels. Use tools like life cycle assessments or environmental impact assessments to quantify and analyse the environmental footprint of the operations.
- Evaluate Social Practices: Assess the social practices and impacts of the agribusiness. This may include evaluating labour conditions, worker safety, community engagement, and adherence to social responsibility standards. Conduct interviews, surveys, or on-site visits to gather information and insights from workers, stakeholders, and local communities.
- Analyse Supply Chain: Assess the sustainability of the agribusiness's supply chain. Evaluate the practices of suppliers and subcontractors, ensuring they align with sustainable production principles. Consider factors such as responsible sourcing, traceability, and transparency in the supply chain.
- Set Improvement Targets: Based on the gap analysis and assessment findings, establish specific improvement targets and goals for the agribusiness to achieve sustainable production. These targets should be measurable, time-bound, and realistic. They can cover areas such as reducing resource consumption, implementing best practices, adopting sustainable technologies, and enhancing stakeholder engagement.
- Implement Action Plans: Develop and implement action plans to address the identified gaps and achieve the sustainable production targets. This may involve making operational changes, investing in new technologies, training employees, establishing partnerships, and engaging with stakeholders. Monitor progress regularly and adjust as needed.
- Monitor and Report: Establish a monitoring and reporting system to track the agribusiness's performance and progress towards sustainable production. Regularly measure and report on key indicators and metrics related to sustainability. This helps to ensure accountability, transparency, and continuous improvement.
- Seek Certification or Verification: Consider seeking certification or verification from recognized sustainability standards or organizations. This can provide external validation of the agribusiness's compliance with sustainable production practices and enhance its credibility in the market.
- Continuous Improvement: Sustainable production is an ongoing process. Encourage a culture of continuous improvement within the agribusiness, fostering innovation, learning, and adaptation to evolving sustainability challenges and opportunities.

By following these steps, agribusinesses can assess their compliance with the conditions of sustainable production and take concrete actions to enhance their sustainability performance. The issue of food waste is a prime example of the benefits of lean production and consumption. It is socially and economically absurd that one-third of the world's food goes to waste while 800 million people suffer from hunger [9,10]. This problem is also environmental, as almost 20% of global greenhouse gas emissions come from agriculture, and the use of fertilizers and pesticides harms natural ecosystems [11,12]. To address this issue, people in the economy and associations are working to reduce the volume of unsold products. Relevant trends have prompted the international community to explore new options for lean consumption and sustainable production, such as joint consumption, sharing economy, gift economy, and circular economy. In Ukraine, the agricultural price index for January 2022 was 106.1%, a weighted average that reflects changes in prices in all areas of agricultural product sales, including to processing enterprises, markets, and the public [12].

LLC "NIBULON" is a notable example of a successful transition to sustainable development among enterprises, as the largest producer and exporter of agricultural products. Their sustainable development policy aims to ensure the efficient use and reproduction of natural resources, environmental protection, and safety of production, and building a closed production cycle that utilizes secondary raw materials. As the world faces increasing environmental challenges and the need for responsible consumption and sustainable production, it is

crucial to continue developing innovative solutions and promoting sustainable practices in all areas of the economy.

Table 1. Agricultural sales price indices from 2013 to 2022 (%). *Source: Author.*

Month													
year	January	February	March	April	May	June	July	August	September	October	November	December	In a year
2013	102	102	102	100	96	96	96	89	92	100	101	111	91
2014	94	109	111	116	105	94	98	98	92	102	109	109	145
2015	118	117	115	99	96	100	97	97	92	102	115	103	166
2016	98	106	100	102	101	97	101	94	96	103	102	103	107
2017	102	103	101	102	98	99	100	96	99	103	102	102	111
2018	102	101	103	103	97	96	98	99	100	99	100	101	104
2019	101	100	97	100	97	97	100	94	92	101	100	101	86
2020	102	105	102	113	95	101	97	98	107	106	108	106	153
2021	110	104	107	98	99	94	95	97	98	101	104	104	116
2022	106												106

That is, at the entrance to our research under the influence at socio-economic impact of COVID-19 dependent factors for agribusiness, it is advisable to propose the following goals of sustainable development:

- overcoming poverty in all its forms and everywhere
- overcoming hunger, achieving food security, improving nutrition and promoting sustainable agricultural development
- ensuring a healthy lifestyle and promoting well-being
- ensuring comprehensive and equitable quality education and encouraging learning opportunities.
- ensuring gender equality
- ensuring the availability and rational use of water resources and sanitation for all
- usage of renewable energy
- decent jobs and economic growth
- innovation and infrastructure
- reducing inequality
- responsible consumption
- protection of the planet
- ensuring life under water
- ensuring life on earth
- peace and justice
- cooperation to achieve goals.

Table 2. Volumes and average prices of agricultural products sold by enterprises in January 2022 (%). *Source: Author.*

Product name	**Sold**		**Average sale prices**	
	kt	% to the corresponding period of 2021	UAH per t (k pcs)	% to the corresponding period of 2021
Cereal and leguminous crops	3662.2	17.9	6675.6	108.5
Wheat	621.9	150.7	7686.1	108.6
Maize for grain	2908.1	181.7	6438.1	109.3
Barley	88.3	234.4	6907.1	114.6
Rye	14.7	272.4	5176.0	107.5
Seeds of oil crops	826.8	150.6	17691.4	105.9
Soya beans	104.0	122.9	16045.6	111.9
Rapeseed and colza	3.7	285.4	20834.4	167.6
Sunflower seeds	717.4	155.3	17904.8	104.4
Potatoes	22.0	163.1	5248.0	84.2
Vegetables	16.4	93.6	15486.1	154.0
Fruits and berries	13.8	145.0	7584.1	78.3
Live agricultural animals	79.7	102.4	40312.6	125.0
Cattle	8,8	89.6	45814.2	134.5
Pigs	36.2	95.5	39080.7	120.2
Poultry	34.6	115.6	40214.2	128.5
Milk of agricultural animals of all species, raw	232.9	107.0	10825.2	108.4
Poultry eggs in the shell, M pcs	491.2	92.5	2260.8	103.2

The weighting base for aggregating these changes is the actual volume of sales of the relevant types of products for the reporting period, at socio-economic impact of COVID-19.

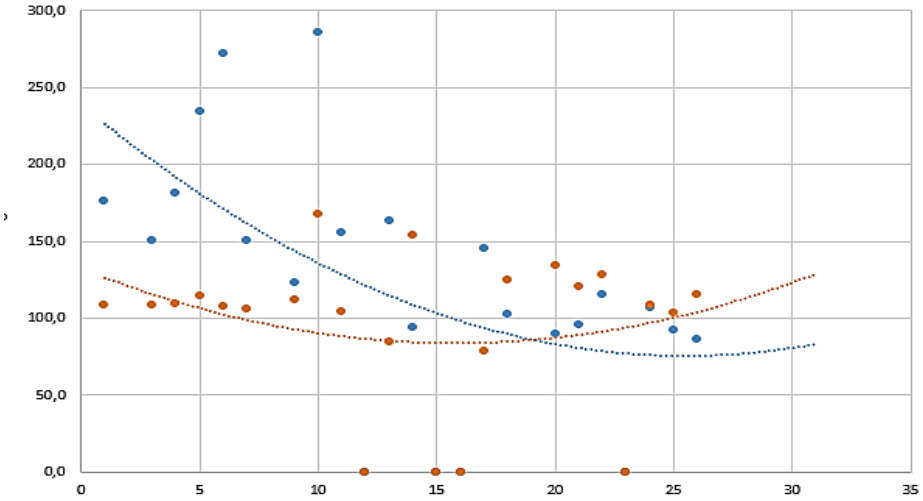


Figure 5. Changes dynamics in the price of agricultural products and sales. *Source: Author.*

The results of the study revealed the following. The current crisis caused by the military actions, COVID-19 pandemic, mostly actualized the already existing challenges between humanity. That is why an important task today is the need to form solutions that will bring benefits at all socio-economic levels. Therefore, the transition to the eco way will allow enterprises to combine favourable business results with measures to protect the environment, based on the model of sustainable development. Results and discussion on managing responsible consumption and sustainable production enterprises in glocalization conditions involve analysing the outcomes and implications of implementing the methods. Here are some key points to consider:

- Improved Environmental Performance: Effective management of responsible consumption and sustainable production enterprises leads to improved environmental performance. By adopting sustainable practices, such as reducing emissions, conserving resources, and minimizing waste, businesses can significantly reduce their ecological footprint and contribute to environmental preservation.

- Enhanced Reputation and Brand Image: Implementing responsible consumption and sustainable production practices can enhance a company's reputation and brand image. Consumers increasingly value environmentally conscious businesses and are more likely to support and engage with companies that demonstrate a commitment to sustainability. This can result in increased customer loyalty, market share, and positive word-of-mouth.
- Cost Savings: Sustainable production practices often lead to cost savings in the long run. By optimizing resource usage, improving energy efficiency, and minimizing waste, businesses can reduce operational costs and enhance their financial performance. This demonstrates that responsible consumption and sustainable production can be economically beneficial for enterprises.
- Market Opportunities: The growing demand for sustainable products and services presents significant market opportunities for businesses. By aligning their offerings with responsible consumption and sustainable production principles, enterprises can tap into the expanding market of environmentally conscious consumers and gain a competitive advantage.
- Collaboration and Knowledge Sharing: Managing responsible consumption and sustainable production enterprises in glocalization conditions often involves collaboration and knowledge sharing among various stakeholders. Building partnerships with suppliers, customers, and industry peers can foster innovation, best practice sharing, and collective efforts to address sustainability challenges.
- Socio-economic Impact: Responsible consumption and sustainable production have positive socio-economic impacts. By promoting fair trade, supporting local communities, and adopting ethical business practices, enterprises can contribute to social development and improve the well-being of stakeholders.
- Resilience to Global Challenges: The COVID-19 pandemic highlighted the importance of responsible consumption and sustainable production in ensuring business resilience. Enterprises that had already implemented sustainable practices were better equipped to adapt to the crisis and mitigate its impacts. This underscores the significance of sustainability in building resilience to global challenges.

Overall, managing responsible consumption and sustainable production enterprises in glocalization conditions yields positive results, ranging from environmental benefits and cost savings to market opportunities and social impact. By embracing sustainable practices and considering local contexts, businesses can contribute to a more sustainable future while reaping various economic and reputational rewards.

Impact

Managing of responsible consumption and sustainable production enterprises in glocalization conditions is a crucial aspect of today's globalized world. As the interconnectedness between local and global factors continues to shape our economic, social, and environmental landscapes, it becomes imperative for businesses to adopt sustainable practices that prioritize responsible consumption and production. One of the key reasons why this topic holds immense importance is its direct impact on environmental sustainability. Irresponsible consumption patterns and unsustainable production processes have led to significant environmental challenges such as climate change, pollution, deforestation, and resource depletion. By managing responsible consumption and sustainable production, businesses can play a vital role in mitigating these challenges. They can minimize waste generation, reduce carbon emissions, conserve natural resources, and promote the use of renewable energy. By integrating sustainable practices into their operations, businesses can contribute to the preservation of ecosystems, protect biodiversity, and create a more sustainable future for generations to come. Moreover, the topic of managing responsible consumption and sustainable production is closely linked to social responsibility. It encompasses fair labour practices, ethical sourcing, and community engagement. Businesses that prioritize responsible consumption and sustainable production uphold the well-being and rights of workers, support local communities, and promote social equity. By ensuring fair wages, safe working conditions, and respecting human rights, these businesses create a positive impact on society. They contribute to poverty alleviation, empower local communities, and foster inclusive economic growth. Economically, managing responsible consumption and sustainable production brings forth numerous benefits. Organizations that embrace sustainable practices often witness increased operational efficiency, cost savings, and innovation. By optimizing resource utilization, adopting circular economy principles, and implementing green technologies, businesses can reduce their production costs, enhance productivity, and gain a competitive edge.

Furthermore, responsible consumption practices can stimulate market demand for sustainable products and services, new business opportunities and fostering economic growth. In the context of glocalization, managing responsible consumption and sustainable production requires businesses to understand and adapt to local contexts while addressing global sustainability goals. It necessitates engaging with local stakeholders,

considering cultural norms and preferences, and adhering to local regulations. By incorporating glocalization principles, businesses can effectively meet the unique challenges and opportunities presented by diverse markets and communities. This approach allows for the localization of sustainable practices and the integration of global best practices, resulting in more impactful and contextually relevant outcomes. Managing responsible consumption and sustainable production enterprises in glocalization conditions is of utmost importance in today's world. By prioritizing environmental sustainability, social responsibility, economic resilience, and glocalization principles, businesses can contribute to a more sustainable and equitable future. The adoption of sustainable practices not only benefits the planet and society but also enhances long-term business success and reputation. It is imperative for businesses to embrace their role as agents of change and proactively engage in managing responsible consumption and sustainable production. The paper of managing responsible consumption and sustainable production is of great importance in the modern economy. In the context of globalization, where the world economy is increasingly integrated and dependent on other countries and regions, the implementation of the principles of sustainable development becomes essential for ensuring long-term economic stability and growth.

Companies that adopt a responsible approach to production and consumption can gain competitive advantages such as increased consumer loyalty, improved brand reputation, lower costs through increased resource efficiency and reduced environmental footprint. Governments can also support the development of responsible consumption and sustainable production through various programs and measures such as tax incentives, subsidies, regulation and incentives for innovation and technological development. Thus, the theme of managing responsible consumption and sustainable production is important for economic development and long-term sustainability, and its impact on the economy can be significant, both for individual enterprises and for states.

The following sustainable development and consumption trends have been observed in the world over the past 5-10 years:

- Increased interest in clean energy sources such as solar, wind, and hydro energy.
- More countries taking measures to reduce greenhouse gas emissions, including the implementation of emissions taxes.
- Growing interest in sustainable and responsible consumption, including the use of products and services produced with consideration of environmental and social aspects.
- Increase in the volume of waste processing and reuse of materials in production.
- Development of technologies that allow to produce goods and services with less use of resources and energy, such as 3D printing.
- Increase in the number of companies incorporating sustainable development principles into their business plans and strategies.
- Growth of the sharing economy and popularity of taxi services and bike and e-scooter rentals.
- Increase in the number of companies implementing corporate social responsibility programs and supporting the communities in which they operate.
- Development of eco-tourism and rising interest in clean food sources such as organic products.
- Increase in global cooperation and implementation of common standards and norms for sustainable development and consumption.

The paper on managing responsible consumption and sustainable production has a significant impact for several reasons:

- Environmental Impact: The paper addresses issues related to responsible consumption and sustainable production, which are crucial for mitigating the negative environmental impacts of industrial activities. By promoting sustainable practices, the paper contributes to reducing resource depletion, pollution, and greenhouse gas emissions, thus fostering a more environmentally sustainable future.
- Social Impact: Responsible consumption and sustainable production have social implications. By emphasizing the importance of ethical business practices, fair trade, and community engagement, the paper highlights the positive social impact that businesses can have on local communities and stakeholders. This includes improving working conditions, supporting local economies, and fostering social equity.
- Economic Impact: The paper recognizes the economic significance of responsible consumption and sustainable production. By implementing sustainable practices, businesses can achieve cost savings through resource efficiency, waste reduction, and energy conservation. Furthermore, the paper acknowledges the growing market demand for sustainable products and services, indicating potential

economic opportunities for businesses that embrace sustainability.

- Policy and Governance: The paper contributes to the discourse on policy and governance frameworks for responsible consumption and sustainable production. It highlights the need for governments and regulatory bodies to create an enabling environment that supports and incentivizes sustainable practices. The research presented in the paper can inform policy development and shape strategies for sustainable development at local, regional, and global levels.
- Knowledge Advancement: The paper adds to the existing knowledge and understanding of managing responsible consumption and sustainable production enterprises. By exploring the factors, initiatives, and challenges involved in implementing sustainability practices, the paper provides insights and recommendations that can guide businesses, researchers, and policymakers in their efforts to promote sustainability.
- Awareness and Education: The paper raises awareness about the importance of responsible consumption and sustainable production among a wider audience. It educates readers about the environmental and social consequences of unsustainable practices and highlights the benefits and opportunities associated with adopting sustainable approaches. By disseminating this knowledge, the paper contributes to building a more informed and environmentally conscious society.

The paper's impact lies in its contribution to addressing pressing environmental and social challenges, informing policy development, fostering economic opportunities, advancing knowledge, and raising awareness about the importance of managing responsible consumption and sustainable production. Looking at the perspective of managing responsible consumption and sustainable production in the context of globalization, several key aspects can be identified regarding its significance for the development of Ukraine and the world. Firstly, Ukraine and the world are facing population growth and increasing consumer demands, which pose a threat to environmental sustainability and natural resources. Managing responsible consumption and sustainable production allows for a balanced approach to resource utilization and reduction of negative environmental impact. Secondly, adopting innovative approaches to responsible consumption and sustainable production creates opportunities for the development of new business models and entrepreneurship. This contributes to the creation of new jobs, attracting investments, and supporting economic growth. Thirdly, managing responsible consumption and sustainable production promotes the improvement of people's quality of life and social justice. This entails ensuring the accessibility of environmentally friendly products and services for all segments of the population, as well as achieving a fair distribution of benefits from sustainable development. Ukraine, with its developed agricultural sector, holds significant potential for implementing responsible consumption and sustainable production practices. Encouraging ecological agricultural practices, supporting eco -conscious enterprises, and promoting the use of renewable energy sources are just a few means through which Ukraine can contribute to sustainable development.

Overall, managing responsible consumption and sustainable production in the context of globalization is essential for ensuring environmental sustainability, economic prosperity, and social justice. It represents a crucial perspective for both Ukraine and the world, enabling a more resilient and balanced future.

Conclusions

Managing responsible consumption and sustainable production has become increasingly important in the context of glocalization - the simultaneous localization and globalization of economic and social activities. Enterprises that adopt sustainable production and responsible consumption practices are better equipped to adapt to changing market conditions, meet the demands of customers and stakeholders, and enhance their reputation and competitive advantage. Moreover, enterprises that manage responsible consumption and sustainable production can contribute to the achievement of global sustainable development goals, such as reducing carbon emissions, promoting social equity and protecting the environment. Sustainable production practices can also lead to increased efficiency and reduced waste, resulting in cost savings and increased profitability. In glocalization conditions, enterprises that prioritize responsible consumption and sustainable production can establish themselves as responsible global citizens and improve their access to global markets. These enterprises can also leverage the opportunities presented by new technologies and digitalization to innovate and improve their sustainability practices. Overall, managing responsible consumption and sustainable production is critical for enterprises to achieve long-term success and contribute to sustainable development in the globalized economy. Study of the driving forces of the development of the world economy and factors that cause itsactivation, have been the subject of research by economists for many centuries. However, different approaches to determining the category of development in general economic system concepts of construction of the world

economy lead to the need to group and generalize existing interpretations. Given the current situation in the world in general and in Ukraine in particular, there is a need changes in priorities and development principles of both the state and a separate sector of the economy. The basis of a new one it is necessary to lay down principles of development policy that would ensure the interaction of man and nature, maintained a sufficient level of economic benefits, considering the limited resources and regenerative capabilities of the environment.

Therefore, the need to transition to a model of responsible consumption and sustainable production development is generally recognized. Managing responsible consumption and sustainable production is essential for achieving a more sustainable and equitable future. This article has highlighted the importance and relevance of this topic, particularly in the context of glocalization conditions where global and local factors intersect. The results and discussion have demonstrated that effective management of responsible consumption and sustainable production enterprises can lead to positive outcomes. These outcomes include improved environmental performance, enhanced reputation and brand image, cost savings, market opportunities, and positive socio-economic impacts. Furthermore, the collaboration and knowledge sharing among stakeholders play a crucial role in driving sustainability initiatives forward. The paper has emphasized the need for businesses to adapt their strategies and operations to meet the specific cultural, social, and environmental contexts in which they operate. It has underscored the importance of stakeholder engagement, sustainable supply chain management, circular economy principles, green technologies, education and awareness, regulatory compliance, and collaboration. The impact of the paper extends to environmental preservation, social development, economic benefits, policy and governance frameworks, knowledge advancement, and raising awareness. It contributes to the ongoing discourse on sustainable development and offers insights and recommendations for businesses, researchers, and policymakers. In conclusion, managing responsible consumption and sustainable production is not only a moral imperative but also an economic opportunity. By embracing sustainable practices, businesses can drive positive change, minimize their environmental footprint, contribute to social well-being, and position themselves as leaders in the evolving marketplace. It is crucial for enterprises to recognize the importance of responsible consumption and sustainable production to create a more sustainable and prosperous future for all.

Conflict of interest
There are no conflicts to declare.

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NEW CONCEPT OF DIGITAL INNOVATION ECOSYSTEM IN BOOSTERING CIRCULARITY DEVELOPMENT TWILIGHT OF TRADITIONAL BROKERAGE OF INNOVATION

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Highlight
The article deals with the new paradigm of circularity brokering in context of the current socio-economic and IT megatrends of development.

Abstract
The aim of the paper is to identify the direction of evolution, the conditions of organisation and the impact of the new concept of digital innovation ecosystem in boostering circularity development. The traditional model of innovation brokerage and the new circularity broker paradigm in the development of the circular economy is presented. The authors discuss the circularity broker as an IT interface, equipped with wide range of IT tools, and above all, self-learning applications with AI elements. The circularity broker is accompanied by its watch dog, i.e., a set of IT tools used to search, process and transfer information dedicated to specific stakeholders, exactly when they need this information. The concept of circular brokerage is anchored in the area of the regional clusters dedicated to circular economy development.

Keywords
a broker of innovation; circularity; megatrends; interface.

Introduction
The role of brokerage has been conceptualized in literature already in the twentieth century as relationships bridge the gaps between social, business and academia worlds. Duncan J. Watts [1] and Mark S. Granovetter [2] stated that the essence of brokerage is an “intensive” search for information about a specific opportunity versus an “extensive” approach, exploiting well known revenue streams of homogeneous information, specific for only one activity. People used to focus on activities inside their own group and on the single activity, what impacts the gaps in information flow between groups, or more simply - creates structural holes [3]. The information or knowledge that cannot be transferred to other actors is kept - consciously or not - by its possessor

and maintains its original value. Brokerage entails bridging structural holes, i.e., “joining previously unconnected parties to facilitate coordination, collaboration and the pursuit of common goals” [4]. Brokering, defined in this way is seen as a revolutionary opportunity for the development of innovation and technology by facilitating the flow of dedicated information between industry and scientists and establishing stable, long-term relations, beneficial for both sides. Therefore, innovation or technology brokers get their chances to be a promoter of innovation.

Innovation broker as a profession appeared on the labor market in 2006 and was defined as an intermediary/ agent in the innovation process between science and industry. As part of his duties, the innovation broker was to assist in disseminating information about new technologies and inventions in scientific institutes and about the needs of enterprises in the field of new products, technological processes, work organization, etc. An important task of broker was advising on fundraising [5]. For two decades, innovation brokering has been identified as a profession, hence - the innovation or technology broker was a concrete man, practicing this profession.

Innovation or technology brokers in the EU and US were bounded especially with universities. The task of the innovation broker was to obtain data from scientists, research groups as well as entrepreneurs about their information needs or about their offers, and then - to select, process and transfer the tailored information to the appropriate recipients. The innovation broker was expected to also use information sources such as scientific publications, industry magazines, conference presentations, trade fair offers, etc. Therefore, effectively fulfilling such wide-ranging and extremely complicated tasks by innovation and circularity brokers is a challenge indeed. In Guidance on Innovation Procurement (2021/C 267/01) [6] the problem of how to mobilize innovation brokers was discussed. The European Commission states that the links between companies, including start-ups and innovative SMEs, offering innovative solutions on the one side, and public buyers, on the other side, are often weak and do not arise spontaneously. Innovation brokers, as being a part of the overall innovation life cycle, are expected to build or strengthen the ecosystem of innovation. Within the above Guidance, the EC suggests that brokers should e.g., advise public buyers on how to join the networks to share knowledge, exchange good practice and communicate to the market (e.g., market consultation, joint commitment for future innovation procurement). A literature review of innovation brokerage practices and analysis of the authors' experience with innovation and technology brokering indicate that we should create a new brokering paradigm that aligns with current socioeconomic mega trends [7].

How does the new paradigm of circularity brokers address the circular development megatrends?
Innovation in the circular economy is considered an essential factor for achieving development while reducing resource consumption. This is confirmed by researchers both on the ground of theory: The green economy, Green growth, Decoupling the growth, Degrowth, or steady-state economy [8–10]. Accordingly to the European Parliament (EP) definition [11], that “circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible”. In other words: circularity means that you should strive to minimize the generation of waste, and if the product's life is coming to an end, the materials from which it was made should be reused, repairing, refurbishing and recycling, thus - returned to the market. You should look for ways to use them again in order to create additional values. The circular economy paradigm implementation helps to replace the traditional, linear economic model, based on a “take-make-consume-throw away” pattern, consuming large quantities of natural resources, materials and energy.

In practice, the circular model of socio-economic development should imply reducing waste to a minimum. It is in line with the concept of the waste hierarchy as given in Figure 1.The main idea of the waste hierarchy model is to prevent/avoid things becoming waste in the first place [12]. It is essential and the most preferred option in the waste hierarchy. Less waste means less need to reuse products, less disposal and most importantly, less waste at landfill sites.

The European Commission's 2008 Waste Framework Directive [13] introduced the term “4R”: Reduce, Reuse, Recycle and Recover. Since then, researchers have proposed R - frameworks beyond the 4Rs, such as 6Rs [14] or even 9Rs [15]: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, Recover [6].

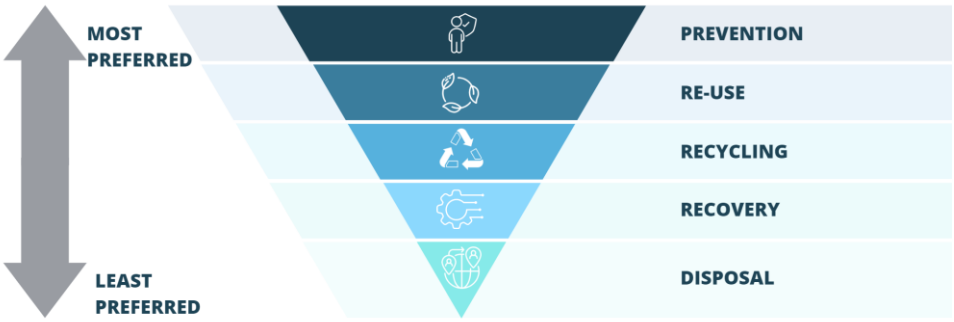

Figure 1. Traditional Waste Hierarchy Concept. *Source: Authors, on the basis [12].*

How does the new paradigm of circularity brokers address the on-demand development megatrends? On-demand economy is defined as the instant and pervasive access to goods and services, tailored to meet the individual's needs [16]. In the last decade, social and economic habits have changed dramatically. The immediacy of our connected world, thanks to instant communication, media and trade, powered the sense of entitlement of all B2B and B2C market participants to immediately satisfy needs [17,18].

On-demand economy megatrend is radically changing the way we transact in the market at the global level and revolutionizing business models, in which companies manage their production and service delivery. At the same time, individuals are radically changing their lifestyle. Under pressure of the On-demand economy rules, decision making processes, concerning both daily and long-term issues, purchases and interactions with the labor market are changing. They must be faster and should consider the rapid pace of changes in the market. The on-demand economy will experience exponential growth in many aspects of the economy and social life, e.g., the amount of every-day information processing. This new paradigm shift is analogous to the disruption imposed by the internet boom. Now, our needs and desires become instantly achievable through the speed and convenience of execution just as the Internet revolutionized the way we acquire knowledge in the late 1990s. The implementation of the on-demand economy paradigm and the reorganization of the global market enable or facilitates new processes of production, delivery or organization, but fundamentally redefines the size, scope and role of industry. For sure, information technologies development and dissemination are essential for these changes.

We can see how digital facilitation contributes to an exponential increase in the speed of transactions, expanding the pool of potential service providers and sellers. Online technologies are a tool to change the way and rate of participants' engagement in a particular transaction. Therefore, in the conditions of an over-exponential growth of available information, on-demand economy, equipped with ICT communication tools, building and maintaining an industrial symbiosis becomes problematic. There is no need any longer to be bound by long-term contracts, while the economic world offers volatile opportunities that are easy to take advantage of. However, a fundamental asset is to have access to an information base, tailored to our needs and, what is more important, competence on how to use it, facing on-demand economic challenges.

How the new paradigm of circularity brokers addresses the collaborative development megatrends? Already in 2016, the European Parliament noticed, that "The arrival of collaborative economy is associated with many benefits for consumers and the economy as a whole" [19]. Collaborative economy is defined [17] as "a marketplace where consumers/clients create specific nets to meet their wants and needs and consists of giving, swapping, borrowing, trading, renting, and sharing products and services for a fee, between an individuals or companies who have something and an individuals or companies who need something - generally with the help of a web-based intermediary". A collaborative economy may also be known as a "shared economy," "sharing economy," or a "peer-to-peer economy." Tempo of implementation of the collaborative economy paradigm, which is observed in last few years, was affected by two complex groups of causes [20]:

- firstly: i*ncreasing public awareness*: growing concern about climate change and growing interest in environmental issues - extreme heat waves and droughts caused by climate change, forest fires, hurricanes, floods, etc.;
- secondly: g*lobal economic and social crises*: because of the Covid-19 pandemic, traditional, long supply chains have collapsed and in many areas of the economy there has been a turn towards a centripetal direction, i.e., local, quasi-autarkic economic development, based on the local potential, including underused resources, better waste management and social inclusion. The war in Ukraine and in the consequence the embargo imposed on Russian energy resources caused a crisis on the energy market and consequently on the food market. Inflation has risen dramatically all over the world.

The Collaborative economy could be an answer to the above-mentioned global challenges. Five key sharing sectors (P2P finance, online staffing, P2P accommodation, car sharing and music/video streaming) have the potential to increase global revenues from around $15 billion now to around $335 billion by 2025. In the UK, these five sharing sectors could generate revenues of around £9 billion by 2025 [21]. It is worth to quote a statement of Veronique Laury, CEO of Castorama [22]: “Most retailers missed the first revolution in retail that digital technology brought: e-commerce. I am determined not to miss the second one: which I believe is collaborative consumption. We will not be just a retailer in the future – we will be an organization helping you to improve your home.”
The Collaborative economy and collaborative consumption are driven by the development of information, communication and cloud computing technologies, growing consumer awareness, the creation of collaborative online communities as well as social media trading/sharing [23].
Collaborative Economy sectors differ from traditional ones in three basic features [21]:

- business models are hosted via digital ICT platforms that combine demand and dynamically share bandwidth in real time;
- transactions are made through various methods that offer access instead of full ownership, such as: sharing, subscription, resale, swap and P2P;
- shoppers like individuals, but as well as companies and local administrations are more comfortable and fell more connected and locally anchored, being provided with products in a way that involves deeper social interaction than traditional methods of trade and exchange.

The Collaborative economy results in the so-called social inclusion, engaging not only the main stream of social potential in the implementation of the principles of the Circular economy, but also activating "by-social potential" and “by-regional potential” [24].

How does the new paradigm of circularity brokers address the app-driven development megatrends? Starting in 2008, Apple set the cornerstone for the app-economy vision and coined its widely touted and trademarked slogan "There's an App for that." The app economy ideas quickly migrated to Android and mobile platforms. Since then, tens of billions of mobile apps have been designed and downloaded. Generally, the app-driven economy refers to the range of economic activity performing in digital space and surrounding mobile applications. Mobile apps and cloud computing technology created new opportunities for entrepreneurs and changed the way business is done. Cloud computing technology gives users access to storage, files, software, and servers through their internet-connected devices: computers, smartphones, tablets, and wearables [25].

Already in 2012 Ray Kurzweil, the Google engineer and futurist said in an interview with the Wall Street Journal, entitled “Technology and the New, Improved You”, that "*A kid in Africa has more technology at his disposal than the president of the United States did 15 years ago*" [26]. A dramatic increase in the number of new business platforms, as well as in smartphone connected consumers, simplify and secure purchase flows, enables explosion of new types of business models, represented by such business as: Uber - the largest transport company without its own cars, Alibaba, Amazon - the world's largest wholesalers without its own stationary stores, Airbnb – the largest tourist network without its own hotel base and many other cases. The digital transformation, guided by the app-based economy, is speeding up changes in the global socioeconomic environment. It has a significant impact on many areas of life, including private life and social inclusion, social activity, but also public administration, industrial structure and business networks [27].

Essential to an app-economy and a collaborative economy as well as an on-demand economy and finally – a circular economy development is business platform, managed by a company or group that acts as an intermediary to facilitate consumers’ ability to rely on each other. Hence, new brokers of circularity

are expected to support on-demand, collaborative and first of all – circular economy development. The feasibility of these complex tasks is possible only when properly tailored IT computing tools are implemented in the circularity ecosystem. Thus, in the new brokering of circularity paradigm, current development trends are orchestrated.

In line with the new paradigm of brokerage, the brokers of circularity should be defined as the interfaces between all stakeholders of the regional or local circularity development. Their main tasks are translation the different languages [28] of the several entities and align information needs with outputs [29]. The broker as interface is not understood any longer as an external person or even an external institution to the organization or company, but rather as its internal officer, equipped with the IT toolkit for dealing with the information of the organization needs just in time and addressing its specific demand. On the other hand, a circular broker [12] as an interface should have easy access to database with full information convenient for boostering a regional circular development. We are talking about two-way access here: the broker should be able to use the database for his specific purposes, but also provide information to the database himself. The other brokers will be able to use such data immediately.

Methods

Analysing global socio-economic trends, the global climate crisis and the resource crisis are determining revolutions in the organisation of markets, influencing the reorganisation of political objectives at every level of government and shaping new patterns of social behaviour. These changes create a unique demand for innovation. This demand affects businesses, citizens, and authorities. Hence, the paper makes the research assumption that we are facing the twilight of traditional innovation brokerage. Consequently, the following research hypothesis was stated and discussed: The complex nature of the circular economy calls for a specific type of brokerage. It requires one that can create and spread innovations by providing remote, direct access to market partners and straightforward advice.

A triangulation of research methods was used to verify the research hypothesis and realise the adopted objective. This hypothesis was verified based on the results of the research: (1) diagnostic (reactive), (2) desk research (non-reactive) and (3) case study analysis.

The first, diagnostic research, was carried out based on the Frontsh1p project (Horizon 2020) and concerned the identification of conditions for the functioning and implementation of the circular economy at the level of the circular cluster. Their subject matter covered: identification of legal and legislative barriers to CE implementation; market failure in CE; incentives for CE; Green Public Procurement; interoperability of databases useful for CE; and conditions for optimising the public governance model for CE. The results of these studies are not the direct subject of this paper, but they served the authors to conceptualise and formulate the aim of the paper and the research hypothesis.

The results of the desk research and case study are the direct subject of analysis in this paper. The desk research analysed scientific publications, reports, and legal resources. They focused on innovation brokering for creating and spreading innovation and transferring technology in the circular economy. The case study analysis was based on 5 case studies of institutions - innovation brokers. From a spatial perspective, the analysis focused on institutions directly influencing the area of the circular cluster in the Lodzkie Region.

From a functional perspective, purposive selection was used in this case to obtain the opinion of innovation brokers regardless of the sector of activity and type of ownership of an organisation. The research was carried out at the following institutions:

- Technology Transfer Centre of the University of Lodz (public entity, R&D unit),
- Research and Innovation Centre Pro-Akademia (non-governmental organisation, R&D unit),
- Foundation for Enterprise Development (non-governmental organisation, training, and consulting unit).
- Technopark Lodz (government public entity, regional development agency);
- Center for Innovation and Technology Transfer of the Medical University (public entity, R&D implementation unit).

Case study research was carried out using in-depth interviews (IDI). The main research (IDI) aim was to gather experiences and opinions on the effectiveness of innovation brokers' work, employed in the interviewed institutions. These assessments were more than critical, although the institutions participating in the interviews

emphasized that the low effectiveness of brokering in the traditional sense was the result of the brokerage formula not being adjusted to present-day economic, technological and, above all, information challenges.

Results and discussion

Circular economy (CE) and a special role of circularity development brokers' topics include developing waste management that promotes new business models, design thinking, and a more productive approach to consumption and production, according to current research. Since the industrial revolution, we have lived in a linear economy [30]. Transition is necessary to move away from the linear economy that has been prevalent since the industrial revolution. Current research [31,32] highlights the importance of circular economy (CE) principles, which encompass innovative waste management practices, the adoption of new business models [33,34] and another efficient approach to consumption and manufacturing [35,36]. The linear economy follows a "take-make-dispose" model, where resources are extracted, transformed into products, and eventually discarded as waste. This approach leads to resource depletion, environmental degradation, and the accumulation of waste [37]. In contrast, the circular economy aims to decouple economic growth from resource consumption by promoting the principles of reduce, reuse, recycle, and regenerate [38,39]. It emphasizes the importance of designing products and systems that are durable, repairable, and easily recyclable, thereby minimizing waste generation.

In this ecosystem, circular economy principles are seamlessly integrated with digital technologies. This synergy gives rise to creative solutions that have the potential to generate cost savings. In addition, it aims to improve resource management, reduce waste, promote sustainable economic growth and open new avenues for income generation. As companies transform their traditional business models into digital ones, they prioritize resource allocation and seek to minimize resource consumption, thus adapting to the principles of the circular economy. This shift is critical to their long-term viability and growth in the market. Digital technologies play a key role in facilitating this transition by enabling efficient tracking, monitoring and sharing of resources. They enable businesses to move smoothly along the path to circular practices. This shift can lead to cost savings, better resource management and new revenue streams. In addition, digital technologies such as the Internet of Things (IoT), artificial intelligence (AI) and block chain play a key role in enabling transparency, traceability and accountability within the circular economy. They enable real-time data collection, analysis and decision - making. This improves resource optimization, waste reduction and circular supply chain management. Accordingly, the European Commission's Circular Economy Action Plan explicitly recognizes the importance of digital technologies to accelerate circulation. They enable real-time data collection, analysis and decision - making. Third, the convergence of digital technologies and sustainable development is very important in various industries.

Digital platforms support the development of innovative business models and collaborative ecosystems. For example, sharing and rental arrangements make optimal use of resources and reduce waste. Products, business models and value chains can be systematically redesigned using various digital technologies, resulting in lower material and energy consumption. This strategy allows customers to engage in the circular economy by providing them with information about the origin of items and their impact on the environment throughout their life cycle.

The predominant approach to Circular Economy focuses on technical and engineering aspects [15] or economic and environmental ones but tends to overlook the social dimension of CE. Existing reviews of CE have highlighted deficiencies in the current conceptualization, specifically the lack of emphasis on social and institutional dimensions, which are considered crucial for the comprehensive development of the CE concept [40]. The advancement and execution of CE initiatives are heavily dependent on broad-scale collaboration within society [41].

Transitioning to a circular economy requires systemic changes across various sectors and stakeholders [42]. The new paradigm of circular brokers activities involves rethinking production processes, implementing sustainable waste management practices, fostering collaboration among businesses, policymakers, and consumers, and promoting innovative technologies and business models. The adoption of circular economy principles can bring numerous benefits, including the reduction of waste generation, the preservation of natural resources [14], the creation of new business opportunities, especially in virtual reality, and the mitigation of environmental impacts [13]. It can also contribute to the development of a more sustainable and resilient economy addressing the current global socio-economic megatrends. A transition, according to Schlossberg [43],

is any event or non-event that results in altered relationships, routines, assumptions, and roles. It is vital to emphasize that perception is important in transitions since an event, or non-event, satisfies the criteria of a transition only if the individual experiencing it defines it as such. In a multi - level governance, the roles of transition may vary depending on factors such as the timeframe, content, and context of the transition. To comprehend the significance of a shift for a certain individual, the kind, context, and impact of the transition must be addressed [44]. Transition brokers have a vital role in facilitating and coordinating the shift towards a circular economy [38]. They act as orchestrators within the system, actively participating in processes of change and striving to establish alliances and collaborations among diverse stakeholders.

Monitoring and evaluating the progress of the transition is another crucial aspect of the process. Assessment of the impact of circular initiatives, identify valuable insights, and share best practices with relevant stakeholders. Overall, transition brokers act as catalysts for change by bringing together stakeholders and resources, facilitating collaboration, and driving the transition towards a circular economy. Their impartial stance, expertise, and ability to navigate complex systems make them instrumental in accelerating the adoption of circular practices and fostering sustainable and resilient economies. An essential function of transition brokers is to establish the necessary environment for the desired evolution, identify barriers and opportunities within the current system and work towards overcoming obstacles, creating a condition encouraging circular initiatives. This can involve advocating for supportive policies, regulations, and financial mechanisms that incentivize circular practices. Transition brokers also contribute to the development of impactful circular initiatives. Bringing together a wide range of stakeholders, including businesses, government entities, academia, and civil society, enable to collaborate on the design and implementation of circular solutions. By adopting a neutral standpoint, transition brokers facilitate dialogue, consensus-building, and the co-creation of innovative strategies and projects. Brokers can serve as facilitators, mediators, knowledge brokers, network builders, or project managers [38,45]. Their focus is on fostering collaboration, promoting the exchange of knowledge, and ensuring the effective implementation of circular economy principles.

Brokers can pursue four brokerage strategies [46]:

- coordinate activities or information between distant parties with no immediate prospect of direct introduction or connection;
- proactively maintain and exploit the separation between parties;
- introduce or facilitate existing ties between parties so that the coordination role of *tertius iungens* gradually fades (short-term connection);
- create or encourage interaction between parties while continuing to play an important coordinative function over time (persistent iungens).

Thus, at its core, brokerage is focused on this idea of bringing together people or groups who may not have direct connections, to create value through facilitating interactions. Brokers are expected to bridge gaps, mediate relationships, and provide access to resources or opportunities that would otherwise be out of reach for those involved. They are considered instrumental in promoting innovation, sharing knowledge, and fostering collaboration. While it is widely acknowledged that brokers play a vital role in enabling connections, collaborations, and the exchange of information, the actual realization of their impact leading to success is not frequently observed. However, the belief that brokerage behaviour alone guarantees success is often met with scepticism when examined empirically. While brokers may possess the necessary skills, networks, and knowledge to connect diverse individuals or groups, the outcomes of their efforts can vary significantly. This disparity can be attributed to several factors, including the intricate nature of social interactions, contextual limitations, individual motivations, and the unpredictable dynamics within networks. In other words, the success of brokerage endeavours is influenced by a multitude of complex and ever-changing elements that go beyond the mere act of connecting others.

Brokers act as intermediaries who bridge the gaps between different groups or organizations, enabling the transfer of information, ideas, and expertise [47]. They go beyond simply connecting individuals or groups; they actively work to develop mechanisms and structures that facilitate effective communication across boundaries. One-way brokers achieve this is by developing work practices that promote information sharing and collaboration. They identify and establish common processes, methodologies, and tools that enable individuals from different groups to work together efficiently. These work practices may include regular meetings, workshops, or collaborative platforms where knowledge and insights can be shared. In addition,

brokers create repositories where relevant information and resources are gathered and made accessible to the involved parties. These repositories serve as centralized hubs of knowledge, capturing best practices, case studies, research findings, and other valuable resources. By curating and disseminating this information, brokers enable easier access and transfer of knowledge across groups.

One of the key functions of brokers is to help community members acknowledge and appreciate the perspectives of others. They actively listen to the concerns, values, and aspirations of each community and then translate and convey these messages in a way that can be understood and respected by other communities [48]. This process involves not only language translation but also cultural interpretation, ensuring that the nuances and subtleties of each community's perspective are accurately conveyed. Brokers also create opportunities for dialogue and interaction among community members. They organize meetings, workshops, and other collaborative activities where individuals from different communities can come together, share their experiences, and engage in meaningful discussions. Through these interactions, community members have the chance to learn from one another, challenge their preconceptions, and develop a deeper understanding and appreciation for the perspectives of other communities. Innovation brokers communicate and combine the global world with the local world perspectives. They facilitate and often enable the inclusion of local actors in transnational relationships. However, innovation is rooted, hence synergies are created for both the external environment and the local entrepreneurial environment.

A specific feature of the linear economy is the sectorial structure of business relations and the sectorial concentration of processes. Hence, the typical market mechanism for coordinating innovation processes was clustering in the sense of Porter [49]. Such an arrangement favoured processes of deepening specialisation. This also applies to the broker function and the specialisation of the institutions within which the brokers functioned. These institutions evolved from thematically universal to highly specialise by sector. We observed all these processes and transformations of the brokerage approaches in the entities that were included in the IDI study: Technology Transfer Centre of the University of Lodz, Research and Innovation Centre Pro-Akademia, Foundation for Enterprise Development, Technopark Lodz or Center for Innovation and Technology Transfer of the Medical University of Lodz.

The organisation of the circular economy needs a fundamental change. In a circular economy, it is necessary to seek connections and relationships between sectors. This also implies the need to concentrate but within circular clusters [50]. The logic behind the functioning of a circular cluster is based on the functioning of industrial symbioses and industrial clusters [51].

An innovation broker in this system is essential. While the demand for expertise remains, there is a newfound need for the ability to unite knowledge and partners across different sectors. This fact suggests the need to redefine how an innovation broker is structured and how they function in the circular economy. Due to the considerable acceleration of the dynamics of economic and social processes and the expectation of an immediate response (reaction), the immanent characteristic of the broker today should be, first and foremost, accessibility, or more precisely off-the-shelf. The second predominant characteristic of a broker, which can be inferred from the analysis of trends, preferences and research results, is practical knowledge that can be conveyed in a short and accessible form. In other words, the expectation arises of a broker's non - stop availability, who could handle any number of stakeholders at the same time, without wasting time waiting in line. Thus, other functions such as mentoring or coaching are minimised at this stage.

Accordingly, to the new paradigm of circularity brokerage, the Circular Economy Brokers as an interface are to proactively engage stakeholders and citizens in creating opportunities for circular business and social innovation Figure 2.

The concept of brokerage of circularity addresses four economic megatrends and the Circular Economy Brokers are seen more as a cloud ICT tool then a person dedicated only for circularity development for one or more institutions. In order to achieve high efficiency of circularity development, the geographic area of activity of the circularity broker should be limited to the area determined by the rational use of resources [52,53].

It is a space of circular cluster activity [50,54]. This area should be linked to the region of economic and technological clusters in the traditional understanding of the area of cluster activity [55]. Thus, circularity brokers as a kind of virtual tool will be able to support regional stakeholders and citizens in their activities

for circularity development thanks to:

- easy access to up-to-date, complete and selected information, tailored to the needs of the stakeholder;
- easy transfer, submission and visualization on the platform of individual offers in terms of owned by - products or waste, accessible for sale in the rational and cost-effective territorial coverage;
- access to current market analyses in relation to specific technologies or products from global, European, national and regional perspectives;
- access to the specific cloud platforms and repositories, supported stakeholders in process of circularity development;
- the capability to locate or to find interesting information on regional maps;
- the ability to conduct a self-assessment of the state of implementation of the circularity paradigm in one's own institution using a set of specialized indicators;
- raising awareness and knowledge of circularity on e-learning platforms;
- familiarization with examples of good practices in the development of circularity in various EU regions.

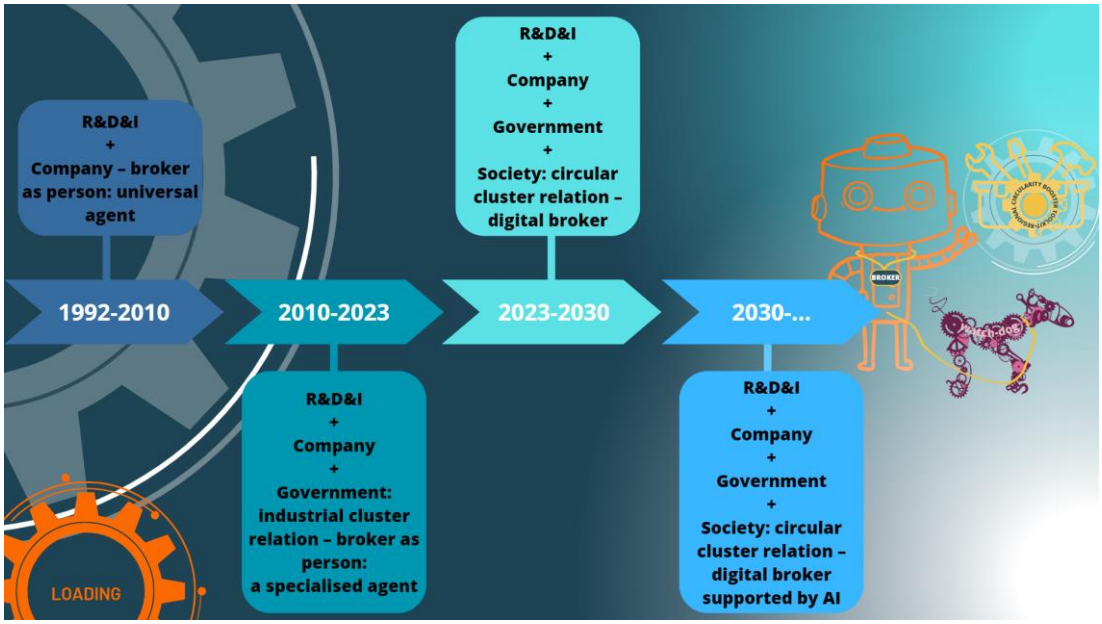

Figure 2. Evolution of the innovation broker function. *Source: Authors.*

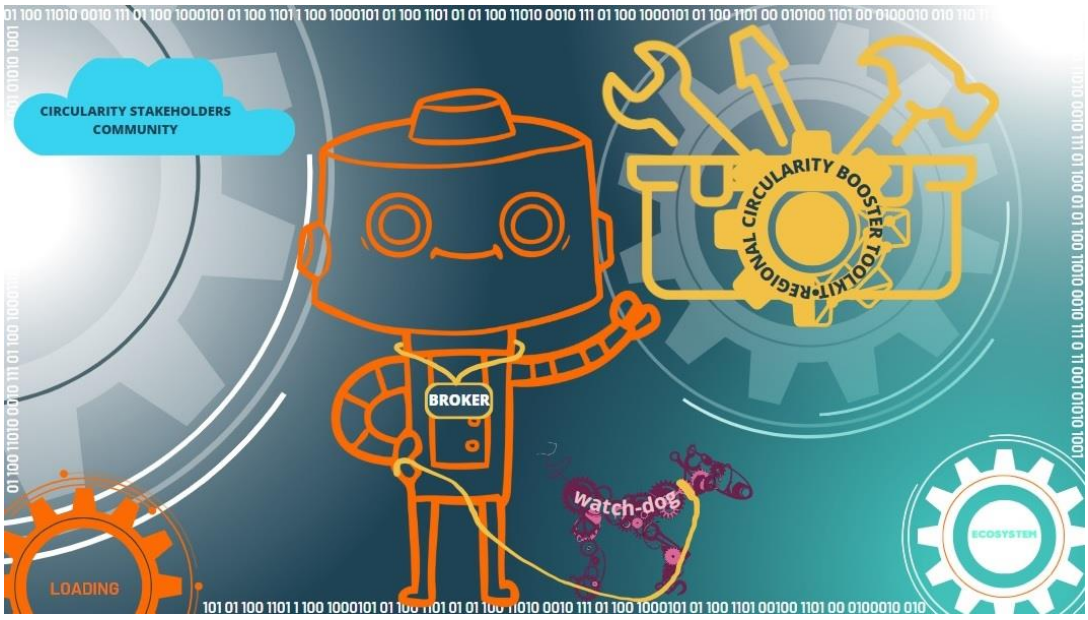

Figure 3. Circularity broker and the watch-dog interfaces among the RCBT. *Source: Authors.*

The regional circularity booster toolkit should provide basic socio-economic and technological information addressing main general questions in terms of circularity development. Among them are selected market analysis, scientific publication in scope of circularity, monitoring system with the circularity self-assessment procedures and for example - the voluntary emission reduction (VER) scheme [56]. Within the H2020 project Frontsh1p [57], there are presumptions of two advanced interfaces elaborated - the Circularity broker and the Circularity watch-dog, facilitating the management of fast data circulation. The mapping tool will enable visualization of a region in a scope interesting for the user, e.g., where the specific waste processing installations are located, where the specific by-products are ready for picking-up, etc.

The Circularity Broker will have his best companion, the circularity watch-dog – an interactive tool for collecting and automatically transferring information to the selected recipients in scope of their identified needs and offers, prepared by circular community stakeholders. Watchdog, which constantly monitors the emergence of new information of a horizontal nature as well, searches for information tailored to the needs of the circularity stakeholder community and (….as a real dog used to do….) "brings" the given information to the Circularity broker. The watch-dog will look after opportunities for the development of local circularity, will track available waste and, more broadly, by-products and by-potential, and after finding it, will announce it loudly. Moreover, it will bring the acquired information to the recipients who are waiting for it. Then, the watch-dog will look after the important data on command from the Circularity broker. In practice, the circularity watch-dog - the interactive tool - will look for, find and immediately transfer data to the identified recipients, guided by a set of appropriate parameters. From technological perspective - the watch-dog should be permanently watching for new resource supply opportunities for companies - materials, waste, by-products and for new, demand for offer of by-products and final products, useful for boostering circular economy development. In particular, the watch-dog interface will follow not only tailored regional recyclers' databases, but also the waste-oriented trade platforms, like e.g., www.mamodpad.wastemaster.pl, offering such waste “raw-materials”. In the area of social engagement in regional circularity development, circularity broker and its watch-dog, are to compile examples of good practices of local society involvement in environmentally friendly activities. The watch-dog will be permanently analyzing internet portals presenting social initiatives in this area and the circular broker will share them with circularity stakeholder community.

The circularity broker, equipped with regional circularity booster toolkit and with its watchdog, as an interface will perform all the tasks described above. It will be challenging to fix the set of keywords that stakeholders use to search for and enter their own data on platform for solving the specific problems. Simultaneously, another challenge will be an establishing procedure not only to protect users’ online privacy, but also to ensure the cyber security of the databases and data processing procedures on the ICT platform, for boostering regional circularity development Figure 3.

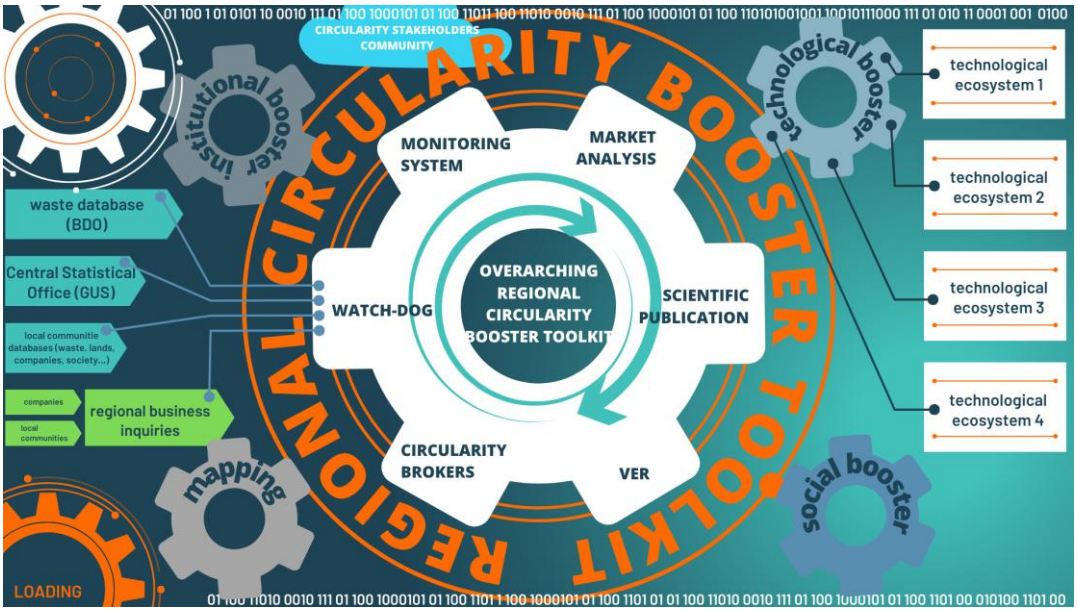

Figure 4. Position of the Circular Economy Broker on the ICT platform for boostering regional circularity development.
Source: Authors.

Circularity brokers can implement rewards and incentive systems. By offering virtual badges, discounts, or loyalty points, these platforms may acknowledge and incentivize individuals who actively participate in circular practices such as recycling, sharing, or purchasing sustainable products. These rewards not only encourage continued engagement but also foster a sense of achievement and pride among citizens.

Additionally, digital brokers provide valuable feedback to citizens based on the data collected through their interactions with the platform. This feedback helps individuals refine their circular practices, identify areas for improvement, and make more sustainable choices. By facilitating this feedback loop, circularity brokers empower citizens to continuously learn and grow on their circular journey. While the concept of circularity brokers as virtual tools is relatively new, there are emerging examples and initiatives that demonstrate their potential to impact social aspects. In addition to the RCBT described above, created as part of FRONTS1P project, here are a few already existing platforms that can be showcasing the impact of circularity brokers on social aspects:

- Sharetribe https://www.sharetribe.com/: Sharetribe is a platform that enables the creation of sharing economy marketplaces, allowing individuals and communities to share resources, services, and skills. It empowers citizens to become active participants in the circular economy by facilitating peer-to-peer sharing and collaboration. By connecting people and promoting resource sharing, Sharetribe fosters social interaction, community building, and economic empowerment.
- Too Good To Go https://toogoodtogo.com/: Too Good To Go is an app-based circularity broker that tackles food waste by connecting consumers with surplus food from restaurants and stores. The app allows users to purchase leftover food at discounted prices, reducing food waste and providing affordable meals. This initiative addresses social issues such as food insecurity, affordability, and access to quality food, while also promoting sustainable consumption and raising awareness about food waste.
- Vinted https://www.vinted.pl : Vinted is an online platform that facilitates the exchange of second-hand goods among its users. It enables individuals to ell items they no longer need, promoting the reuse of resources and reducing waste. Vinted's focus on circularity contributes to social aspects by encouraging a culture of sharing, reducing the consumption of new products, and providing affordable access to goods for individuals and communities.
- Open Food Network https://www.openfoodnetwork.org/: The Open Food Network is an open-source platform that connects consumers with local food producers and farmers. It enables individuals to source fresh, sustainable, and locally produced food directly from producers. By supporting local farmers and shortening supply chains, the Open Food Network fosters community resilience, promotes fair trade practices, and strengthens social connections between producers and consumers.
- Circularise https://www.circularise.com/: Circularise is a block chain-based circularity broker that focuses on improving transparency and traceability in supply chains. It enables companies to share information about the origin, composition, and environmental impact of products while protecting sensitive data. By promoting transparency, circularise enhances social aspects such as trust, consumer confidence, and accountability, allowing individuals to make informed purchasing decisions.

These examples highlight how circularity brokers, in the form of virtual tools and platforms, can contribute to social aspects by fostering collaboration, resource sharing, and access to affordable goods, transparency, and community building. As the circular economy continues to evolve, it is expected that more innovative circularity brokers will emerge, further influencing social aspects in positive ways.

The added value for the local and regional development of the proposed circularity brokering paradigm is access to appropriate, dedicated/ tailored and up-to-date information for the various stakeholders of circularity, e.g., companies, local administration, social cooperatives as well as non-governmental organizations, households and individuals. The Circular Economy Broker as an interface on cloud platform will allow all stakeholders of circularity at the regional level to create opportunities for circular business and social innovation. For local administration, a circularity broker will contribute to creating a beneficial environment for circular economy growth, will facilitate the search for good practices or patterns for how to initiate and support such model of regional development.

The preparation of a circularity broker in the form of an interface on cloud platforms is a prerequisite for the involvement of artificial intelligence in the future. The preparation of a circularity broker in the form of an interface on cloud platforms is a prerequisite for the involvement of artificial intelligence in the future. Artificial intelligence is an opportunity for a widespread, and smooth, transformation towards a circular

economy. AI as a tool to accelerate the transition [58–61]. We already know that AI involvement will be important in areas such as asset management, data and information management, data security, document management, communication management, training and advisory services, market analysis and reporting, design management, infrastructure management and other.

Impact

The concept of digital broker, as analyzing in this article, draws inspiration from mega trends especially sharing economy and through this sheds light on the social aspects involved [18]. Circularity brokers, as virtual tools, can play a crucial role in supporting citizens in transforming into sustainable society. Digital brokers as digital tools offer a range of valuable features and services that empower individuals to actively participate in CE [62]. Firstly, circularity brokers can act as gateways, facilitating citizens' access to various circular services and opportunities. These platforms connect individuals with sharing platforms, repair services, second-hand marketplaces, and sustainable product alternatives. By aggregating and showcasing these options, circularity brokers simplify the process of finding and accessing circular solutions that align with citizens' needs and values. Secondly, they provide features such as online communities, forums, and social networking tools, enabling citizens to connect with like-minded individuals, share knowledge, and collaborate on circular initiatives. Digital brokers also offer measurement tools that allow citizens to track and assess their circular practices. These tools monitor metrics such as waste reduction, energy savings, material reuse, and carbon footprint. By visualizing their progress, citizens gain a deeper understanding of the impact of their actions, which in turn motivates them to further improve their circularity efforts.

Conclusions

The organisation of the circular economy needs a fundamental change of the role of brokerage as a bridge under the gaps between business and industry and academia worlds. The research conclusions in the article confirm that traditional innovation brokers are not effective enough. The brokerage formula is unadjusted to present - day economic, technological and, above all, information challenges, thus the twilight of traditional brokerage of innovation and circularity development is observed. Brokers today should focus on transitioning to a circular economy. This transition requires significant changes across many sectors and stakeholders. The new paradigm of circular brokers activities involves rethinking production processes, implementing sustainable waste management practices, fostering collaboration among businesses, policymakers, and consumers, and promoting innovative technologies and business models. Modern circularity brokers act as orchestrators within the ecosystem of circular economy, actively participating in processes of change and striving to establish alliances and collaborations among diverse stakeholders. The predominant characteristic of a broker, which can be inferred from the analysis of trends, preferences and research results (IDIs), is comprehensive and interdisciplinary but practical knowledge which should be conveyed in a short and accessible form just on time and just on exact demand. No later, no earlier, no more and no less. The demand of circularity brokers' non-stop availability and handling any number of stakeholders at the same time, can be addressed only by the IT interfaces, dedicated and tailored to circular development stakeholders needs.

In conclusion, as a virtual instrument, circularity brokers can foster the actions of both regional stakeholders and citizens involved in the promotion of circularity development. This is achieved by offering straightforward access to timely, comprehensive, and curated data. Furthermore, these brokers facilitate the seamless transfer, submission, and display of individual offerings, which may pertain to personally owned by-products or waste. These assets are immediately available for purchase, and this facilitated commerce happens within a territorially bounded area defined by efficient and reasoned use of resources on cloud-based platforms. The IT circularity brokers can facilitate the access to current market analyses in relation to specific technologies or products from global, European, national and regional perspectives. Summering: the circularity brokers, as virtual tools, can play a crucial role in supporting not only industry in transition from linear to circular economy development, but also citizens in transforming into sustainable society.

Conflict of interest

There are no conflicts to declare.

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