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Content

STUDY ON PERFORMANCE OF A GREEN HYDROGEN PRODUCTION SYSTEM INTEGRATED WITH THE THERMALLY ACTIVATED COOLING

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Highlight
Process for the cost reducing of green hydrogen through the production of cold using the recovered heat from the hydrogen production process.

Abstract
The energy transition is at the centre of research and development activities with the aim to fight against the effects of global warming. Today, renewable energies play a significant role in the electricity supply to the World and their use increases day after day. Because of the intermittency of a large-scale production system generates the need to develop clean energy storage systems. Hence, energy storage systems play is one of key elements in the energy transition. In this perspective, a green hydrogen is defined as an energy carrier thanks to its high energy density in relation to its negligible mass, not to mention its abundance in our environment, and its extraction, which does not contribute to any greenhouse gases. However, the production cost is not negligible. Hence, this work shows a numerical modelling of the heat balance from a green hydrogen production system using a thermal storage in a Metal Hydride (MH) tank for an electrification by Proton Exchange Membrane (PEM) fuel cell integrated into the production of heating, cooling and sanitary hot water (SHW) through the recovery of the heat released by the whole system combined with the technology of thermally activated cooling of an adsorber. This allows demonstrating that the green hydrogen can be an interesting solution according in the hydrogen production chain and in the tertiary sectors.

Keywords
thermal energy; green hydrogen; trigeneration; energy transition; cooling.

Introduction
A reduction of the world's energy consumption is one of the biggest challenges in the fight against the global warming. However, it is especially difficult with a continues grow of population [1] as it results in an increasing demand for energy. Hence, the research on the production and storage of clean energy is developing considerably

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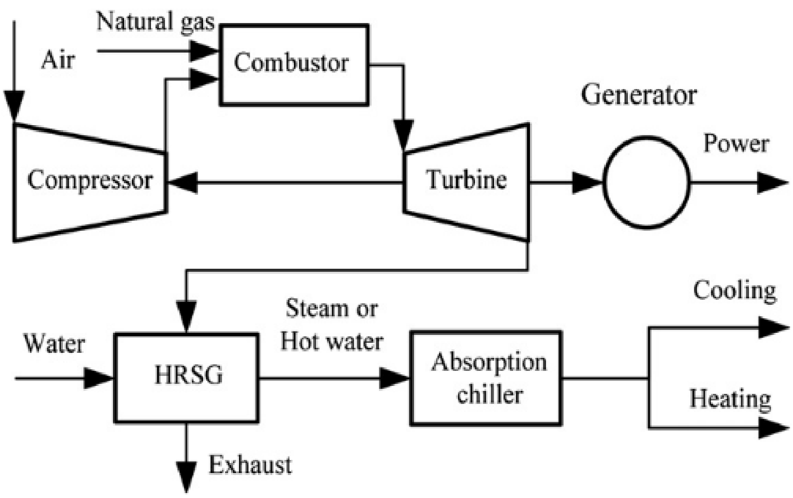
to meet these demands. Therefore, to face these issues, the production of clean energy is growing on a large scale, especially through solar and wind system, leading to need for a development of clean storage systems. In the same strategy of sustainable development, reducing energy losses becomes essential. Therefore, the energy efficient techniques for the energy storage have been developed. Among them are the recovery of waste thermal energy in power plants to cover certain demands in heating and cooling.

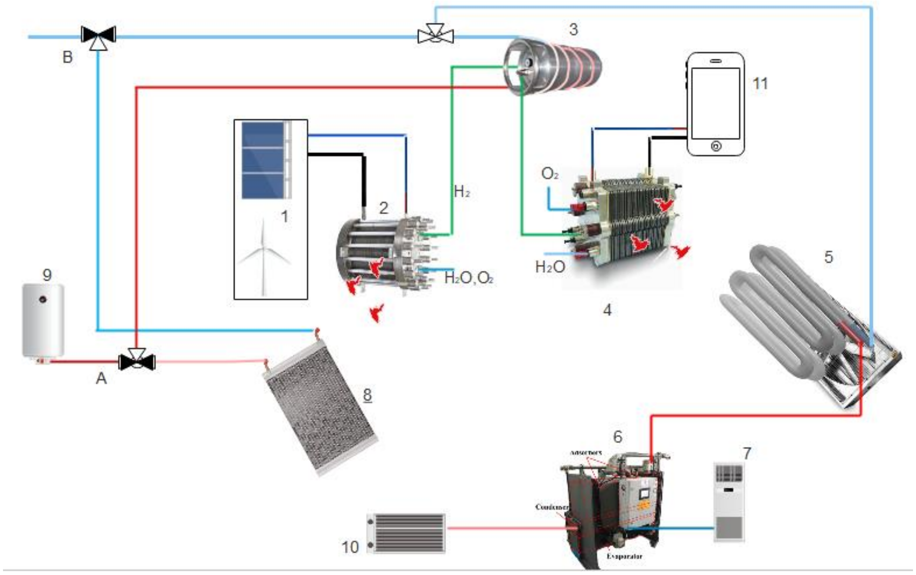
Air conditioning is responsible for almost 15% of the energy consumption today [2] and this percentage is expected to increase considerably by 2050 due to the advance of global warming [3]. Knowing that the most used technology is still the mechanical steam compression cycle, which contributes to greenhouse gases, it is important to develop novel solutions of a cold production using more sustainable systems. In this perspective, techniques of cogeneration and trigeneration were born and they found to be the most frequently used in hospitals, hotels and large public spaces. The combined cooling and heating and power systems (trigeneration) is a technique dating from the 80's, resulting from cogeneration, which itself has more than 110 years of maturity [4]. As can be seen in Figure 1 (a), trigeneration allows the recovery of waste heat from electricity production to produce heat and cooling. As presented by Baudry et al. [5], the building sector is the second largest consumer of energy in the World, far ahead of industry. Furthermore, the need for heating and cooling is relatively important and represents the most energy consuming part in the tertiary sector [6]. Therefore, a trigeneration using thermally activated cooling has been developed over time in several sectors [7].

Considering that the use of green hydrogen is one of the pillars of the energy transition nowadays [8] this article is focus on a trigeneration in the production of green hydrogen to obtain electricity. With the aim of enhancing green hydrogen in the second energy consumer sector through innovative solutions [9], this study takes into consideration all thermal losses of the production system (PEM electrolyser), storage MH and electrification (fuel cell) to cover the needs of SHW production, cooling and heating (Figure 1 (b)), by using the zig-zag configuration exchanger [10] with a better performance. A trigeneration demonstrates several advantages in hydrogen storage because the temperatures released in alkaline electrolysers can reach up to 160°C and in Proton Exchange Membrane (PEM) electrolysis, temperatures are between 60 and 80°C [11,12]. On the other hand, the High Temperature Electrolysis (HTE) allows achieving temperature as high as 200°C. The power-to-hydrogen-to-power cogeneration [13–15] integrated to the novel elements presented herein, the hydrogen as an energy vector in the energy transition can be considered for heating and cooling with a benefits for the energy sector and the environment [16].

The study conducted in this article shows the technological potential of systems based on green hydrogen. Notwithstanding, given the intermittency of renewable energy plants, a proper storage system is the “must”. Hence, several studies concerning the use of green hydrogen as a means of storage have emerged [17,18]. However, the major drawback in the use of green hydrogen is its cost of production. This work contributes to this challenge and shows that enough cooling and heating energy can be produced from the heat that normally would be lost from the power-to-hydrogen-to-power process.



(a)



(b)

Figure 1 (a) Trigeneration according to [16]. (b) green hydrogen production with integrated cooling and heating.

Methods

This work was made using the numerical modelling performed in Matlab R2013a software. MATLAB® is a programming platform designed for engineers and scientists to analyse and design systems and products. The heart of MATLAB is the MATLAB language, a matrix-based language allowing the most natural expression of computational mathematics.

Results and discussion

SWH-Cooling-Heating by green hydrogen heat wasted.

a. Interest of thermally activated cooling in green hydrogen

Green hydrogen technology is well known today and there is a variety of research on this topic [18–21]. The technologies in competition today are Alkaline and PEM [11]. In this study the PEM technology for the storage of green hydrogen is discussed. This technology is relatively easily adaptable to the intermittency of the voltage applied to its terminals; therefore, this solution can be used in case of renewable energies (solar and wind). As shown in Figure 1 (a), one of the important elements in the combined cooling heating and power or thermally activated cooling technology is the process of absorption and adsorption chiller or dehumidifier [22]. Absorption technology is widely used; however, adsorption has the advantage of operating at low temperatures, which is relatively suitable for this study as the temperature lost in a hydrogen production system with PEM technology are rather low. Hence, there is a considerable interest in the thermally activated cooling performed in the adsorption mode. Several works show that adsorption is a thermodynamic phenomenon suitable for low quantities of waste heat .[23,24]

b. Description of the system.

The proposed system, unlike to the previous one [13–15] is equipped with a thermal storage (metal hydride), which presents very interesting aspects in terms of thermal power [25], and an adsorber for a heating and cooling production. The main components, given in Figure 1 (b), used herein are: (5) the tubular heat exchanger to recover heat coming from the fuel cell through forced convection to stimulate cooling on the fuel cell side, (6) the adsorber containing the thermodynamic system, which produces cold, heat, SHW using the hot water coming from (5) or (3) and the cold water coming from the chiller. The proposed adsorber was selected according to the literature [26], and as shown in [23,24,27], the silica gel is an refrigerant fluid efficient in the adsorption of low temperature for trigeneration systems. The system contains the cooling module (7), which diffuse frigid air from the evaporator. The recovery of hot water from the condenser is given as (10). In the tube exchanger (8), the cold water circulates allowing the recovery of the heat coming from the electrolyser, which is modelled according to the characteristics given in the literature [28]. Such produced water can be directly used to cover the needs of domestic applications. In addition, an additional supply of hot water can be obtained from the MH/fuel cell. It is relevant to note that the storage of hydrogen in the MH tank generates a heat, which is

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released during the storage (exothermic reaction). This heat can be used to boil water. The hydrogen storage allows to heat up water to about 65°C from (5), which is later superheated by an external heater to about 150°C and circulates around the MH tank and is used for a desorption (endothermic reaction). Furthermore, the system contains the supply of the electrolyser constituted by a hybrid system (PV solar – wind) (1), the electrolyser (2), the fuel cell (4), and the electrical consumption system (11).

Thermal study.

a. Fuel cell/electrolysis recovery.

This part aims evaluating the water heating temperature at the adsorber inlet. A heat transfer by forced convection, to implicitly cool the fuel cell or the electrolyser, is proposed. The following assumptions, which are in agreement with those proposed in the literature [27,28], were made in this work:

(1) $$R_e = (\rho \times v \times D_h)/\mu$$

(2) $$Pr = (C_p \times \mu)/\lambda$$

(3) $$N_U^{vap} = C.R_e^{vap\,n} \times P_r^{vap\,1/3}$$

(4) $$\mathrm{N_U^{vap}(tur) = 0.023 \times Re^{0.8} \times Pr^{n}}$$

(5) $$\mathrm{N_U^{hw} = 1.86 \times (R_e^{hw} \times P_r^{hw})^{\frac{1}{3}} \times (\frac{D}{L})^{\frac{1}{3}} \times (\frac{\mu}{\mu_t})^{0.14}}$$

where:
N_u - the Nusselt number;
Pr - the Number of Prandtl;
D - the hydraulic diameter;
S and P - the section and the exchange perimeter, respectively;
μ - dynamic viscosity (kg/(m·s));
R_e - Reynolds number;
C_p - the specific heat capacity (J/(kg·K)).

Tables 1-3 summarise values used for the simulation.

Table1. Specifications Adopted for The Simulation. *Source: Author.*

Components	**Rating values**
L_e(PCM)	1.8 m
λ_{PCM}	1.32 W/(m·K)
v_{air}	0.1 m/s
v_{water}	0.15 m/s
μ	0.000891 kg/(m·s)
μ_t	0.000404 kg/(m·s)
L(coil)	2 m
ρ_w	997.63 kg/m^3
λ_{MH}	2 W/(m·K)
λ_{H2}	0.1815 W/(m·K)
λ_{CU}	386 W/(m·K)
λ_{WATER}	0.6 W/(m·K)
μ	0.000891 kg/(m·s)
μ_t	0.000404 kg/(m·s)

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The coefficients C and n in Figure 2 are determined according to equation (6), and γ is a coefficient as given in the literature [29].

(6) $$\gamma = S_p/D$$

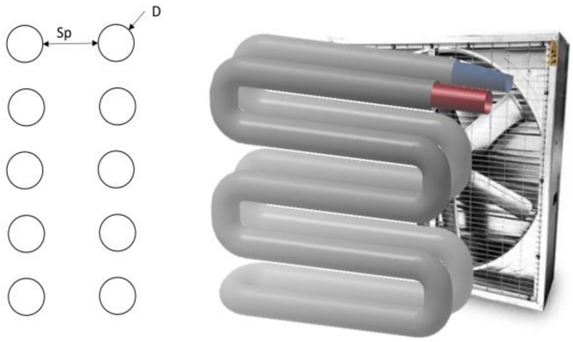

Figure 2. Forced convection heat exchanger (C = 0.386; n = 0.592). *Source: Author.*

Figure 2 represents the heat recovery mode on the electrolyser and fuel cell sides. The air extractor is used behind a coil. The coil and extractor assembly are fitted into a box to promote a heat transfer around the coil. The thermal power φ (W) can be calculated according to the following equations:

(7) $$\varphi = h \times S \times (T_{fuel_{cell}} - T_{serpentine})$$

(8) $$h = \frac{\lambda\, Nu}{D_h}$$

(9) $$D_h = \frac{4\,S}{P}$$

(10) $$\Delta T = \frac{(T_{fuel_{cell}} - T_{serpentine})}{\ln\left[(T_w - T_{serpentine}) - (T_{serpentine} - T_{fuel_{cell}})\right]}$$

where:
D_h - the hydraulic diameter (mm);
N_u - the Nusselt number;
Pr - is the Prandtl number;
S - the section exchange (mm²); *P* the perimeter exchanger (m).

The calculation of the outlet temperature can be expressed by the following equation:

(11) $$T_{out} = \frac{T_{in}}{e^{\frac{K.A}{\dot{m} \times C_W}}}$$

where:
C_p and *C_w* - the specific heat capacities (J/K);
$\dot{m}$ - the mass flow rate and *k* the thermal conductivity (W/(m·K)).
The same principle of heat recover can be used on the electrolysis side.

b. Heat recovery in the metal hydride (MH) tank

As presented in Figure 1(b), the cold water recovers heat from the MH storage system presented in Figure 3. According to equation (12), during storage, a significant amount of heat is released by the adsorption (hydrogen storage). It is important to note that for a desorption, the amount of thermal energy supplied is equivalent because it is an endothermic reaction [20]. The proposed numerical mathematical model is based on the calculation models of heat exchanger and heat transfer as given in the literature [29,30]. For this model, a transfer by conduction through MH - PCM wall - coil – water can be considered. The surface contact between the coil and the MH can be estimated at 1/8 of the lateral surface of the coil, as presented in Figure 3.

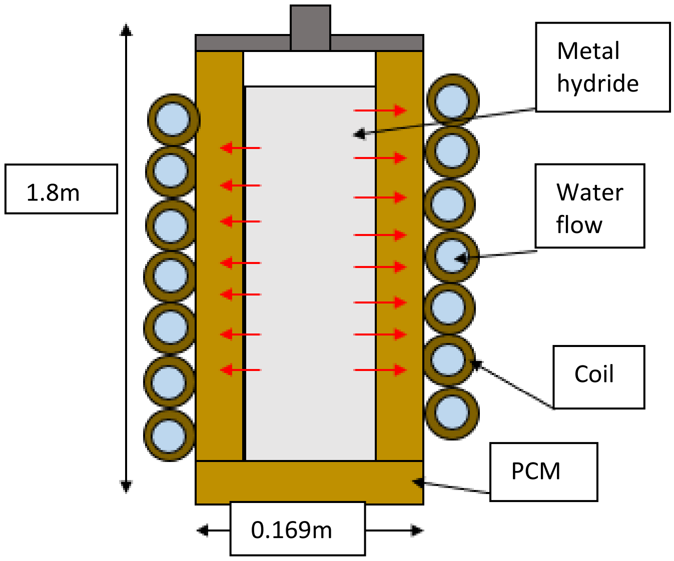

Figure 3. The internal shape and size of the MH tank surrounded by a coil recovering heat. *Source: Author.*

The numerical modelling of the heat production in the MH storage tank by thermal compression is based on different works presented in the literature [18,31,32] The expression of heat released is as follows:

(12)
$$Q_{MH} = \int_{C_d}^{C_a} \Delta H_d(C)dC$$

where:
C_a and C_d - are determined by PCT diagram.
For this study, the values used were C_d = 6 NL/kg; C_a = 143 NL/kg; *Ta* = 20°C; *Td* = 150 °C and ΔH_d is a standard enthalpy of hydride formation expressed in J/mol$_{H2}$.

(13)
$$C_a = C_a(p_L, T_L)$$

(14)
$$C_d = C_d(p_H, T_H)$$

Where:
C - is the hydrogen concentration in MH (mol$_{H2}$/kg);
C_a - the hydrogen concentration during absorption (NL/kg);
C_d - the hydrogen concentration during desorption (NL/kg);
p_h, p_L - the hydrogen pressure during the desorption and absorption, respectively (atm).

The characteristic of the Pressure-Composition-Temperature (PCT) curve determining the reversibility of the storage capacity using the MH LaNi5 alloy is given in Figure 4.
The desorption equilibrium pressure can be determined according to the PCT diagram given in Figure 4 and is expressed by the following function:

(15)
$$P = P_d(C, T)$$

Compression productivity can be expressed as:

(16)
$$V = \frac{m\,\Delta C}{\Delta t}$$

where: m is the mass of MH, Δt the time of the absorption-desorption cycle and ΔC is the productivity cycle.

The van't Hoff relation allowing to express the partial molar enthalpy is expressed by the following relation:

(17)
$$d\ ln\ (P) = \frac{\Delta H_d}{RT} - \frac{\Delta S}{R}$$

where:
T - is the temperature (K);
R - is the universal gas constant (8.314 J/(mol·K))
ΔS - is the standard entropy of hydride formation (kJ/(kg_{H2}·K).

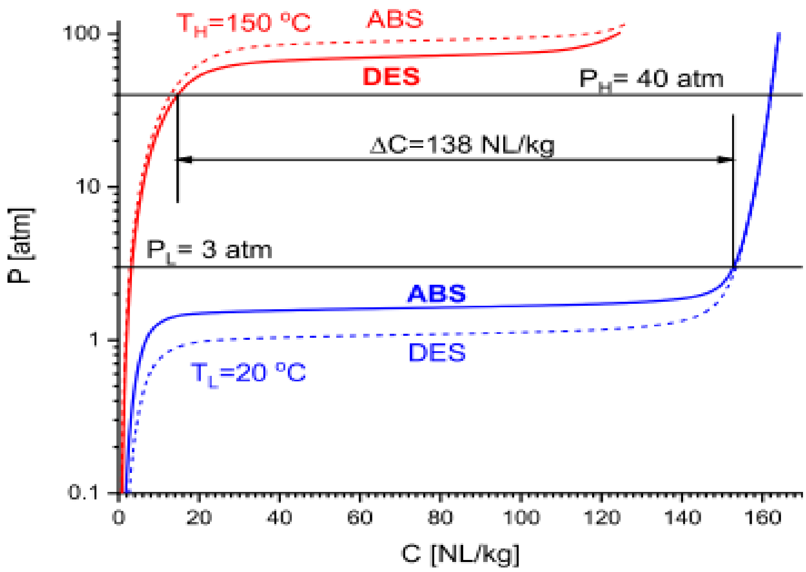

Figure 4. Curve Phase Change Material (PCM) of MH LaNi5. *Source [33].*

Expression of the total heat consumed is equal to the total heat produced during adsorption with the total hydride mass (m) and can be calculated according to the following equations:

(18)
$$Q_{MH} = \delta C \times m \times (\frac{\Delta H_1 + \Delta H_N}{2} + \sum_{k=2}^{N-1} \Delta H_k)$$

(19)
$$\delta C = \frac{C_a - C_d}{N-1}$$

This heat can be also expressed by the equation (20) and can serve to determine the resulting temperature. It is relevant to observe that the temperature released by the MH tank is estimated in the vicinity of the desorption temperature, i.e., close to 150°C. Figure 5 shows the curves of thermal heat release in MH tank, obtained by simulation.

(20)
$$Q_{MH} = m \times C_H \times (T_{MH}^d - T_H^{in})$$

The heat transfer on 1/8 of the coil given in (Figure 5) can be calculated from:

(21)
$$Q_{MH} = \frac{T_{MH}^d - T_p}{\frac{Di}{\lambda_{H2} \times (\frac{D_i^2 \times \pi}{4} \times L_{PCM})}} = \frac{T_p - T_s}{\frac{ln\left(\frac{r_e}{r_i}\right)}{2\pi \times l \times k_{PCM}}} = \frac{T_s - T_{water}}{\frac{ln\left(\frac{r_e}{r_i}\right)}{2\pi \times l \times k_{serpe}}}$$

where
T_{MH}^d, T_p, T_s, T_{water} - are the temperatures of MH, external face of MH tank, the coil internal surface and water

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circulating in the coil, respectively;
k_{serpe} and k_{PCM} - are the heat transfer coefficient of the serpentine and PCM; D_i
r - are the internal diameter and radius and λ_{H2} the thermal conductivity.

Table2. Specifications Adopted for The Simulation. *Source: Author.*

Components	**Rating values**
r_i(coil)	0.077 m
r_e(coil)	0.08 m
$D_i(MH)$	0.149 m
L_e(MH)	1.65 m
r_e(PCM)	0.169 m
r_i(PCM)	0.149 m
L_e(PCM)	1.8 m
λ_{PCM}	1.32 W/(m·K)

Using the equation given in the literature [31], the mass conservation can be calculated:

(22)
$$(\varepsilon \times V_r \frac{d\rho_{H2}}{dt}) = (\dot{m}_{H2} \times V_r) - \overline{m_{el-MH}}$$

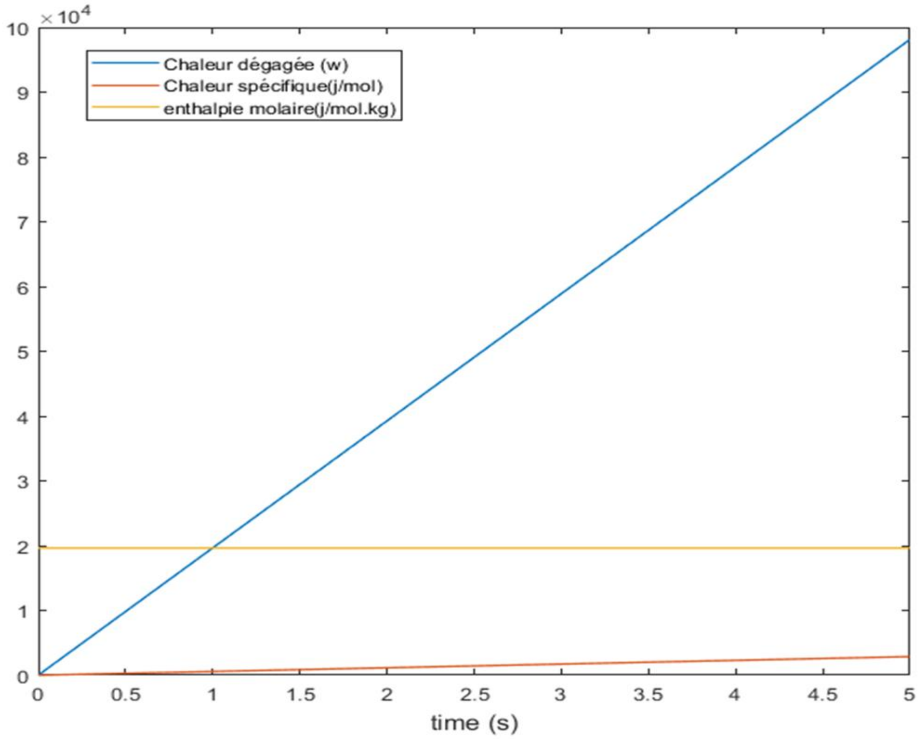

Figure 5. Characteristics of the thermal power in the MH tank(line blue is the heat output (W), line red represents the specific heat (J/mol) and line yellow is the molar enthalpy (J/(mol·kg)). *Source: Author.*

Mass flow of hydrogen circulating between storage tank and fuel cell can be expressed as given here:

(23)
$$\dot{m}_{H2} = \frac{1}{2} N_o \frac{\partial x}{\partial t} M_{H2} R_P$$

where:
$\dot{m}_{H2}$ - the mass flow rate of hydrogen during MH desorption;
$M_{H2}(\frac{kg}{kmol})$ - the molar mass of hydrogen;

x - atomic ratio of the reaction;
Rp - the particle density (H_2 particle/m^3);
N_o - molar mass
ε - the MH porosity.

c. Evaluation of the cooling-heating-SHW capacity by adsorption silica gel

The performance of the adsorber is defined according to the coefficients of performance for cooling and heating, as well as the different affiliated powers. The heat transfer calculations used above with adaptation of the coefficients according to the temperatures can be used to calculate the outlet temperature of the chiller. All the characteristics and data were established according to [24,27,34,35].

(24)
$$Q_{cool} = \sum_{j=1}^{n} \frac{\left[V_{ch}\rho_{ch}C_{ch}(T_{chi}^{j} - T_{cho}^{j})\right]}{n}$$

(25)
$$Q_{heat} = \sum_{j=1}^{n} \frac{\left[V_{w}\rho_{w}C_{w}(T_{wi}^{j} - T_{wo}^{j})\right]}{n}$$

(26)
$$SCP = \frac{Q_C}{M_a}$$

(27)
$$COP = \frac{Q_C}{Q_h}$$

where:
V_{ch} and V_w - volume flow rate in chilled water and hot water, respectively,
ρ_{ch} and ρ_w – densities;
C_{ch} and C_w - specific heats;
T_{chi}^{j} and T_{wi}^{j} - inlet temperatures;
T_{cho}^{j} and T_{wo}^{j} - outlet temperatures of the chilled water and hot water, respectively;
J - data number;
n - number of complete cycles;
Ma - the mass as in the literature [10] used for the calculation of the temperature at the outlet of the chiller.
All the characteristics and data were established according to [23,26,34,36].

Table 3. Specifications Adopted for the Simulation. *Source: Author.*

Components	**Rating values**
V_{H2}^{el}	10000
ρ_{H2}	0.09 kg/m³
$K.A$(evopo+bed adsorption)	2557 W/(m·K) ×1.37 m²+10300
$K.A$(cond+bed desorption)	4115 W/(m·K)×03.71 m²+9850
C_w	4180 J/(kg·K)
ΔS	108.3 J/(mol·K)
R	8.314 kJ/K
v_{air}	0.1 m/s
v_{water}	0.15 m/s

Experiences and analysis

The performed simulation takes into account the parameters from several research papers, namely [27,29,37]. Figure 6 shows the system considered for modelling and according to the numerical modelling the input current in the electrolyser was 52 A and was obtained from renewable source.

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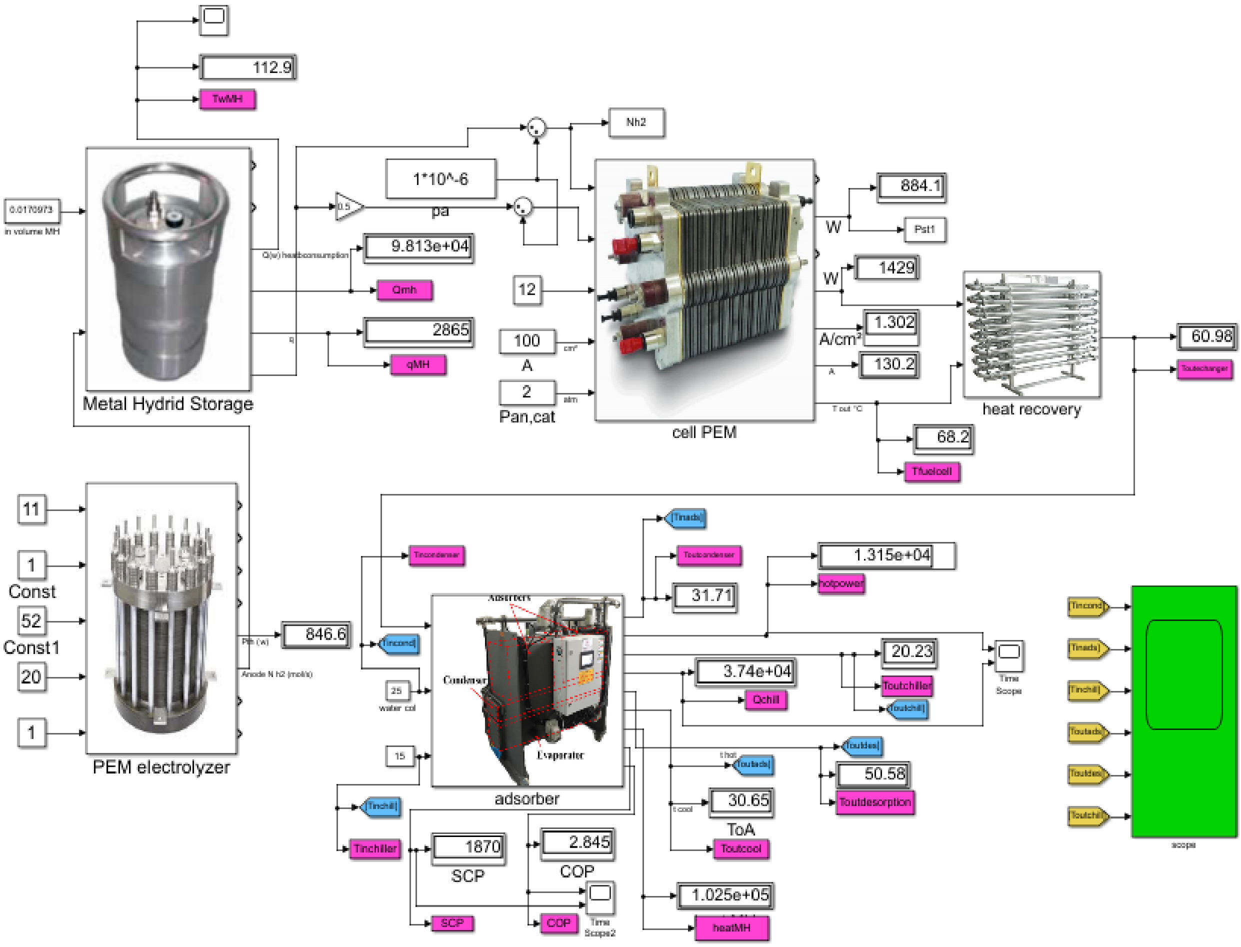

Figure 6. System modelling. *Source: Author.*

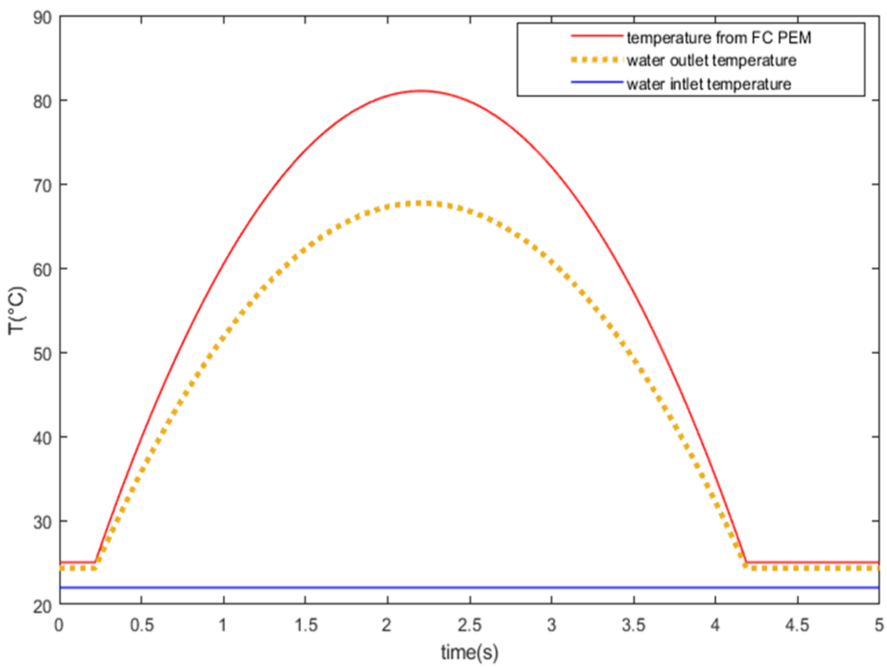

Figure 7. Value of the temperature within the fuel cell resulting from the experimental system. *Source: Author.*

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Figure 7 shows that the temperature variation in the exchanger on the fuel cell side as well as the variation of the temperature in the fuel cell for 50 minutes. As it can be seen, in the fuel cell temperature can reach up to 82°C and at this temperature water leaving a double tubular heat exchanger can reach 68°C.

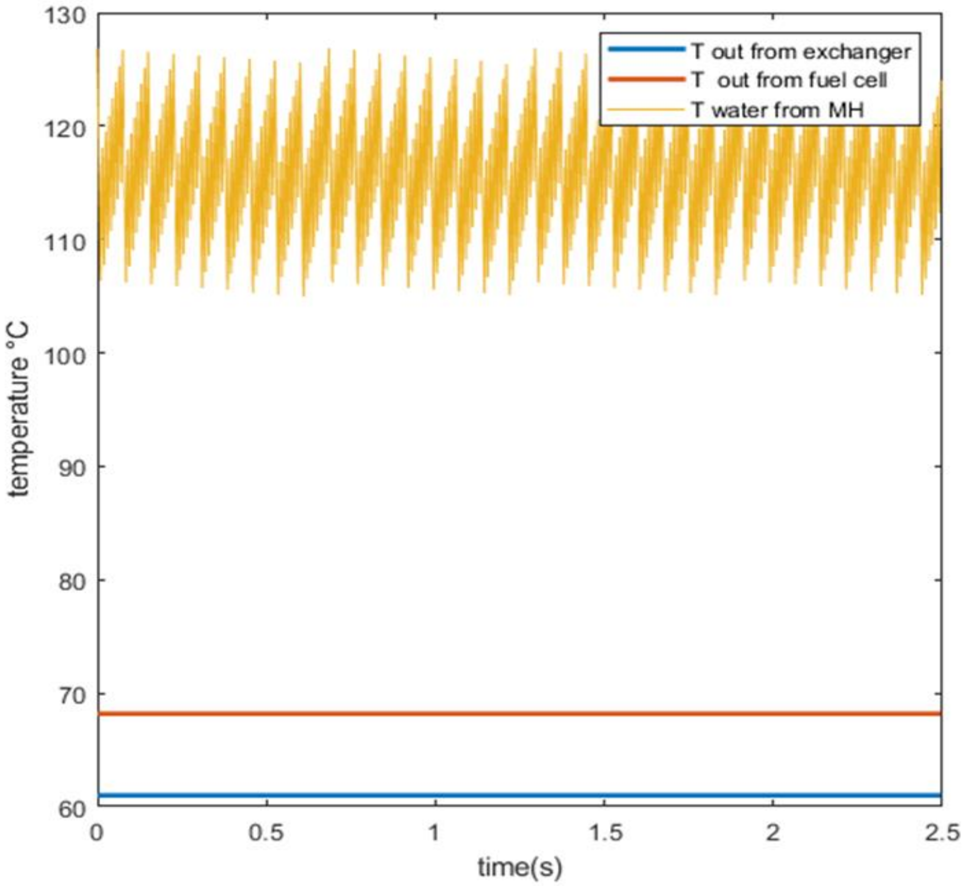


Figure 8. Hot water circuit temperature. *Source: Author.*

Assuming that during the exothermic cycle according to Figure 4, the temperature in the MH tank is as high as 150°C, the water temperature resulting from the exchanger varies between 100 and 120°C. Figure 8 also shows that the use of the MH as a storage medium has a major advantage in terms of thermal power released with temperatures of 110 °C around the tank. It can be noticed that the temperature released by the PEM fuel cell allows to feed the adsorber for the desorption of the silica gel. After the hot water passes through the desorption chamber, a hot water with temperature 50 and 95°C depending on the source can be used.

From Figure 9 the cooling and heating capacities vary proportionally to their efficiency with average values of Qc = 18.691 kW and Qh = 12.273 kW, respectively. Certainly, these powers fit into the energy consumption of heating and cooling systems. Therefore, they can cover the Heating Ventilation and Air Conditioning (HVAC) needs in the building and some industries. Thus, they can play a key role in the achieving the economic feasibility of the hydrogen sector.

Figure 10 presents the efficiency of heating and cooling. The values vary between 0-2 and 0-2000 for heating and cooling, respectively and on average the COP = 1.52 and SCP = 934.5735 (W/kg) can be obtained.

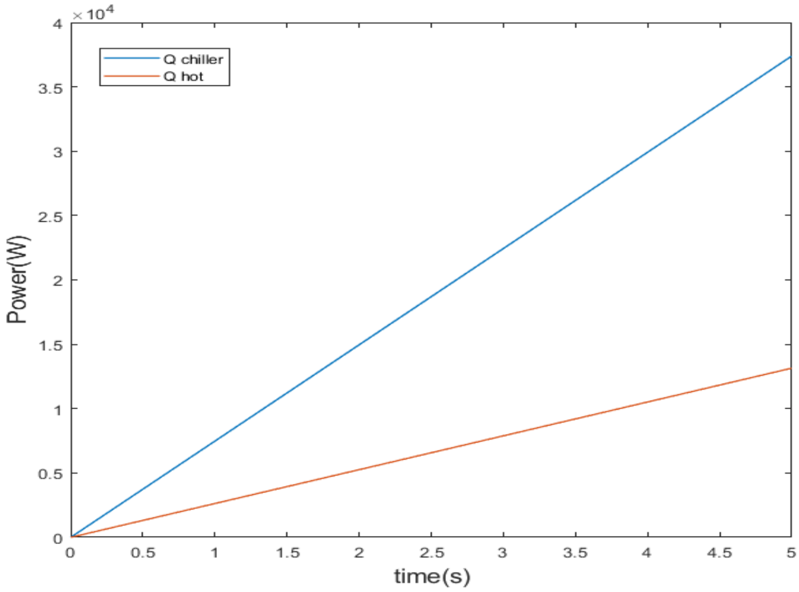
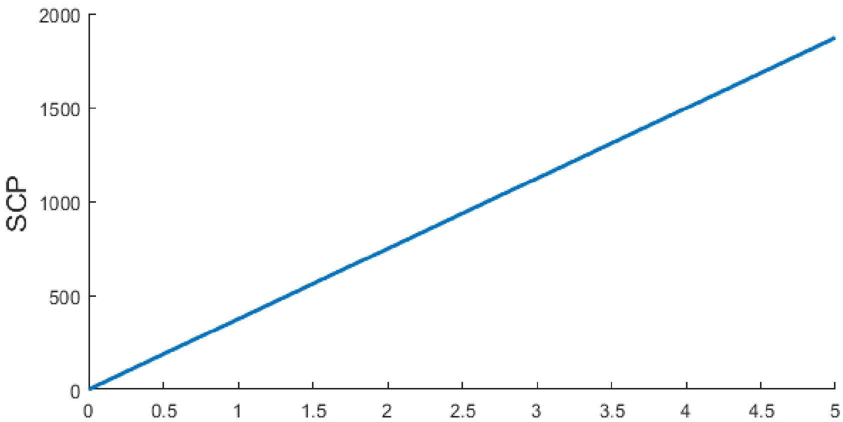
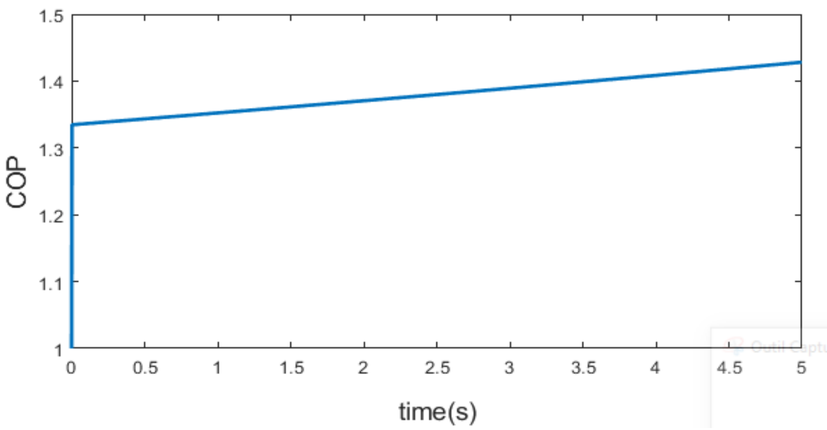


Figure 9. Heating and cooling power. *Source: Author.*



(a)



(b)

Figure 10. Variation of the SCP (a) and COP(b) coefficients for hot form of MH. *Source: Author.*

where:
SCP - is the specific cooling power (W/kg);
COP - is the coefficient of performance.

Impact
This article discusses the integration of a thermally activated cooling system into the green hydrogen production process. Several studies concerning approaches to reduce the cost of acquiring green hydrogen was given in the literature. Among them are cogeneration techniques showing that the heat recovery from the hydrogen production process can be used for, e.g., drying food, or for the water heating. This in turn, generates a financial revenue by reducing the expenses related to acquisition of energy from diverse sources.

Considering the challenges to combat the global warming, one of aspects to be addressed is to use renewable energies to meet the supply needs especially in heating and cooling system. This is especially relevant as both represent the vast part of the energy consumption in the tertiary sector. This work highlights the ability to produce cold from the same heat losses as the one used to meet the need for heating. Considering that the cost of acquisition and use of green hydrogen is high, this study shows that this cost can be reduced by using a heat loss management system adapted to the equipment used. In this study, the use of electrolyser and a fuel cell proton exchange membrane (PEM) for the production of hydrogen and for its combustion is demonstrated. These two elements emit heat, which is potentially lost during the process. In addition, for storage, MH balloons can be considered, and they also contribute to the heat losses. The recovery of all these heats and its conversion into cooling and heating is a key factor from the environmental and economic point of view. It is especially relevant when taken into consideration that the energy consumption related to cold, and heating is not negligible and will increase by 2050. This study shows that it is possible to generate a cooling capacity of up to 18.691 kW in 50 minutes. All the results analysed showed the potential in the combined cold production systems with the process of energy storage by the green hydrogen production. Likewise, this work shows the feasibility of simultaneous production of electrical, thermal and cooling energies from the use of as a source of clean energy. The implementation of this study could allow a rapid insertion of green hydrogen in the tertiary system at a competitive cost with a considerable reduction of greenhouse gases in this sector.

Conclusion
In this article the thermally activated cooling technology applied to a green hydrogen production system using a set of components have been studied
The applied system showed that different potential heat losses of the system allow to produce considerable heating and cooling powers. The thermal power released during the adsorption in the MH tank is the highest along the time of the thermodynamic reactions and it reaches as much as 98 kW with water at 112 °C. On the fuel cell and electrolyser sides a thermal power of 1.4 kW and 0.8 kW, respectively can be obtained. The temperature around the fuel cell is 68°C for 0.884 kW of electricity produced and 0.83 kW of electricity consumed during electrolysis. At the leaving side of the system in the adsorber, the resulting air conditioning and heating temperatures are around 20 °C and 50 °C, respectively.

For a simulation estimated on 1000 s, average powers of 12 kW and 18 kW for heating and cooling, respectively, were obtained. At the same time good coefficients of performance, namely 1.52 and 935 for COP and SCP were achieved, respectively. In addition, the fuel cell can deliver an electrical power of 0.88 kW, which is within the range of the electrical needs of a household of 5 peoples. This allowed to consider that the design of a kit for the tertiary sector or certain industries with the different components used can easily cover the electricity, heating and air conditioning needs contributing to the cost reduction of acquired hydrogen for this sector.

Conflict of interest
There are no conflicts to declare.

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LOGISTICS MANAGEMENT UNDER THE INFLUENCE OF THE COVID-19 PANDEMIC: ECONOMIC, SOCIETAL AND TECHNICAL IMPACT

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Highlight
The paper discusses the miscellaneous impact of the COVID-19 pandemic on logistics management in the carrier, express and parcel services (CEP) market, while analysing the economic, societal, and technical view. At the same time, its results present the solution for the modernisation of the CEP market in Slovakia.

Abstract
The paper aims to analyse the current market in the carrier, express and parcel services market in the EU and Slovakia from the economic, societal, and technical view. It is divided into an introduction, an analysis of the current state in the EU and Slovakia, and a discussion and conclusions. The paper also includes related statistical data presented in the form of graphs. As a result, the development of the CEP market is possible only with a focus on improving the efficiency of delivery, motorisation, unification, expanding the network of collection points and improving the customer experience.

Keywords
logistics management, Slovak Post, carriers, parcels, pandemic, COVID-19.

Introduction

Since early human civilisations, people have needed to transport objects from one place to another. Growth in economic performance and industrial specialisation led to more extensive transport routes. Better use of technology, with advances in science, has allowed the expansion of transport to more places much faster with less effort. The logistics industry connects the economic world, and this connection evolves in response to the changing needs of the market. The emergence of the carrier, express and parcel services market (CEP) is an example of development in the logistics industry. The changing needs of customers and the dynamics of the global economy have forced the logistics market to respond to changes and create new opportunities. One of the market needs was the demand for a faster, better, and safer way to transport industrial goods to facilitate industrial production and consumer goods to satisfy the burning desires of customers around the world [1].

Postal services belong to the services that are considered to have economic impact and are particularly important for the society, whilst contributing to the development of the single EU postal market [2]. Postal services play a key role for EU citizens and businesses in the single market. The postal sector (which includes express services) employs around 1.8 million people in the EU and is an essential source of employment in the EU. The postal and delivery services sector generates annual revenues of 79 billion EUR. Technological developments have disrupted the postal industry, and digital transformation has hit it in two places. Firstly, digital communication tools have replaced traditional communication tools, such as the paper communication, as well as the demand for sending the letters. Secondly, since the number of online shopping possibilities have arisen, the demand for parcels has also increased. These opposing pressures bring challenges for all subjects of the postal sector. However, the postal sector faces the challenges resulting from a lower demand for sending the letters, which is

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supported mainly by the continuous growth in the e-commerce industry. On the other hand, this trend supports new opportunities. As a result, the postal sector of the EU is changing, mainly due to the rise in electronic communication. The parcel segment of the postal market is showing a different state, whilst more and more competitors enter the market of universal service providers (USPs). Such phenomena results in many changes in USPs business models [3,4].

Methods

The paper deals with the miscellaneous impact of the COVID-19 pandemic on logistics management in the carrier, express and parcel services (CEP) market. The paper aims to analyse the current market in the carrier, express and parcel services market in the EU and Slovakia from the economic, societal, and technical view. The main motive for selecting the paper's topic was the success of our previous research from the field of economics and management [5,6] and research conducted by various authors who have dealt with the COVID-19 oriented topic [7,8]. The paper is based on existing European Commission research and data from the Slovak Post. The paper's aim is divided into an introduction, methodology, analysis of the current state in the EU and Slovakia, results, and conclusion. The scientific methods used to analyse and interpret the data included analysis, synthesis, generalisation, induction, and deduction. Statistics were used to determine the changes in variables over time (presented in Figures 1-3), while axe X represents years and axe Y represents percentage change. To demonstrate the importance and significance of the observed changes, the regression analysis was employed. The primary purpose of regression analysis is to examine and characterize the interrelationships between variables. Its task is to find a mathematical function, also called a regression or regression model, that best describes the course of dependence between variables, while we drew inspiration from research that statistically evaluated the effects of the COVID-19 pandemic [9–11]. The results are graphically visualised and are also described in text form.

Results and discussion

The postal industry, as well as other industries, is highly affected by the technological progress. Digitisation influences the postal sector in decline of paper communication and its replacing by electronic communication (e-substitution), and even more, the boom of online shopping causing the rise of the parcel demand. Electronic substitution has occurred by replacing traditional letter mail with means of electronic communication. For example, banks started sending monthly statements via online banking instead of paper copies by post. The drop in demand for letter mail is a consequence of this trend. Historically, the largest senders of letter mail have been public institutions and the business sector for mutual communication between them and citizens. The possibility for the business sector and citizens to communicate with government institutions electronically has become commonplace in many member states. In most Member States, official communication with public authorities is done by electronic and digital means. However, the level of digitisation in this field varies amongst individual Member States. The volumes of essential leaf products in Denmark for 2010-2017 decreased by 93%. The other Member States have undergone varying degrees of electronic substitution and decline in letter mail volumes in recent years. Its volume in the EU decreased on average by 3% per year. The exception is Germany, where letter mail is one of the main communication channels between citizens, the government, and the business sector due to the issue of digital security [12,13].

Digital innovation has opened possibilities for consumers to purchase online. The e-commerce segment in Europe currently represents 344 billion EUR, while in 2018, approximately 69% of European Internet users shopped online. The B2C e-commerce sector is growing in the EU due to higher and more frequent online shopping by consumers. In Europe, e-commerce affects the growth of volumes of parcels and express shipments nationally and cross-border. Between 2013 and 2017, the number of parcels and express shipments grew by 10% per year. The growth of shipments in cross-border traffic was faster than at the national level. In 2016, the value of international trade in shipments amounted to more than 16 billion EUR and 720 million of shipments. The growth of sending cross-border packages is also expected, while it represents the growth from 11% to 18% [14]. The postal market in Slovakia has been fully liberalised since 2012. Slovak Post provides postal services following the granted Postal License and Universal Service (US) Quality Requirements throughout Slovakia through 1 618 branches, including 1 504 post offices (1 342 delivery, 162 delivery), 35 post office partners, 61 postal centres, 14 contractual expenses and five mobile post offices. Out of the total number of 2 928 municipalities in Slovakia, one of the mentioned forms of the Slovak Post branches is operated in 1 449 municipalities [15]. Slovak Post is owned by the state and currently is one of the largest employers in Slovakia (12 700 employees). Cooperation with the state is critical for Slovak Post. In addition to the universal postal service, it includes the payment of benefits and pensions, the provision of e-Government services, the delivery of official documents in paper to

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addressees who do not have an activated electronic mailbox (CADLUD), or the distribution of e-stamps and printing. For the future, the management of Slovak Post has set a new goal – to become the leader in the package delivery market. As part of the recovery measures from 2017 to 2019, the post office increased the prices of postal services four times, leading to a decrease in revenues due to the decline in shipments. However, it still had to operate branches that would not function without the obligation to provide US, because they do not bring profit. In 2019, it prepared a plan to optimise the postal network in 150 locations while complying with the US postal license and quality requirements. The first stage was implemented, in which 29 post offices were cancelled. Still, the Ministry of Transport and Construction of the Slovak Republic suspended optimisation of 120 branches. In the audited period, the Slovak Post recorded fluctuating economic results. In 2017, the economy ended with a net profit of 0.34 million EUR, but in 2018 with a net loss of 4.64 million EUR, the year 2019 already with a net profit of 1.39 million EUR. The reason was persistent problems related to replacing traditional postal services and increasing the competitive environment [2].

Slovak Post, like other traditional postal operators in Europe, has faced an unprecedented change in the market environment in recent years, which is fundamentally pushing for a change in the business model of operation. Interest in letter services is decreasing globally from year to year due to the massive boom in electronification [16].

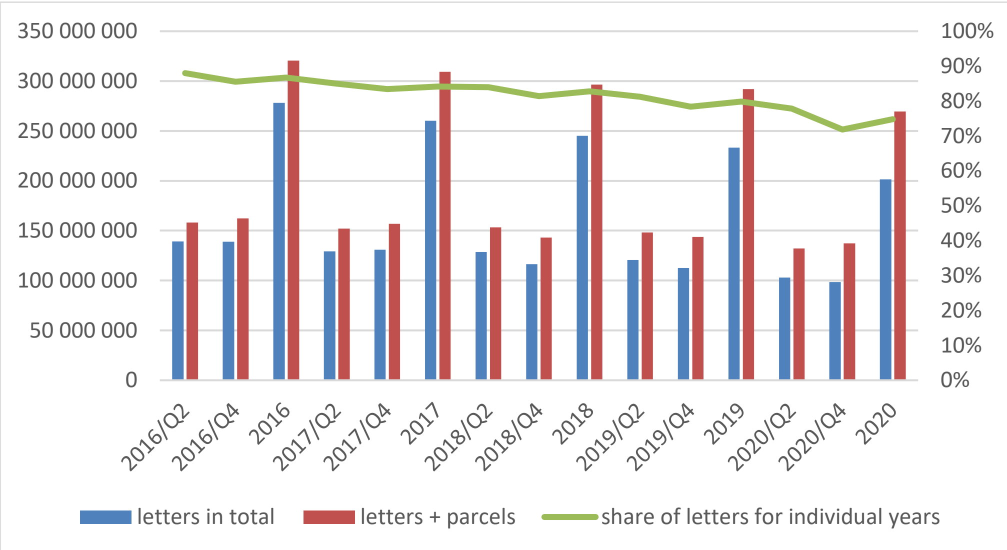

Figure 1. The number of mail items submitted in Slovakia from 2016 to 2020. *Source: [17].*

Decades of slow declines in letter delivery volumes (from 400 million to 100 million per year over the past 40 years) caused by the development of electronic means of communication have been exacerbated by the COVID-19 pandemic in the past two years. This has forced many post office clients to accelerate electronification and abolish physical communication with clients through traditional postal letter shipments. For Slovak Post, this means, of course, further shortfalls in revenue. This is a clear challenge for finding new approaches to delivery [16,18].In other years, the world is experiencing an unprecedented increase in the e-commerce segment, which was also accelerated by the COVID-19 pandemic in the last two years. If we compare the volumes of parcels over the last 40 years, as with letter mail, we find that from the beginning of the eighties until 2016, it was in the Slovak Post's network the same volume of parcel shipments every year, which ranged between 6 and 7 million pieces [17].

Since 2016, the number of parcels had accelerated from 7 million to 16 million parcel shipments (estimated in 2021), when the annual growth rate, especially in the last two years, exceeded 23%. In 2021, the year-on-year growth rate for the first nine months was 21%. The dynamics of the development of this segment in Slovakia and at Slovak Post correlate with global developments and trends [17].

Based on the above facts, it could be assumed that the volume of parcels increased during the COVID-19 pandemic. In addition, we analysed the results published on the website Transport.sk [19] and results of COVID-19 pandemic influence analysis , it could be concluded that the shortfalls in letter shipments are being replaced by growth in the parcel segment [20,21]. The empty circles in Figure 3 represent a prediction; the difference

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between an empty circle and reality is the impact of the pandemic. For example, in Q4/2020, there was a 5.09% difference between reality and prediction. Unfortunately, it is more complicated than that. Apart from the economic side of the matter, which is fundamentally against the Slovak Post, there is a problem in the very essence of the postal service. However, this is not only a problem for Slovak Post but also for postal companies worldwide.

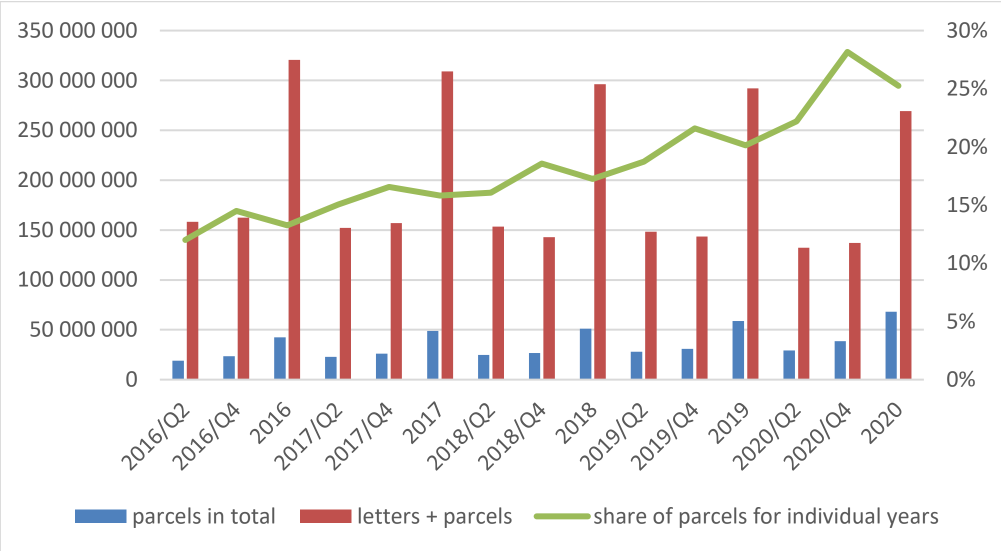

Figure 2. The number of e-commerce packages submitted in Slovakia from 2016 to 2020. *Source: [17].*

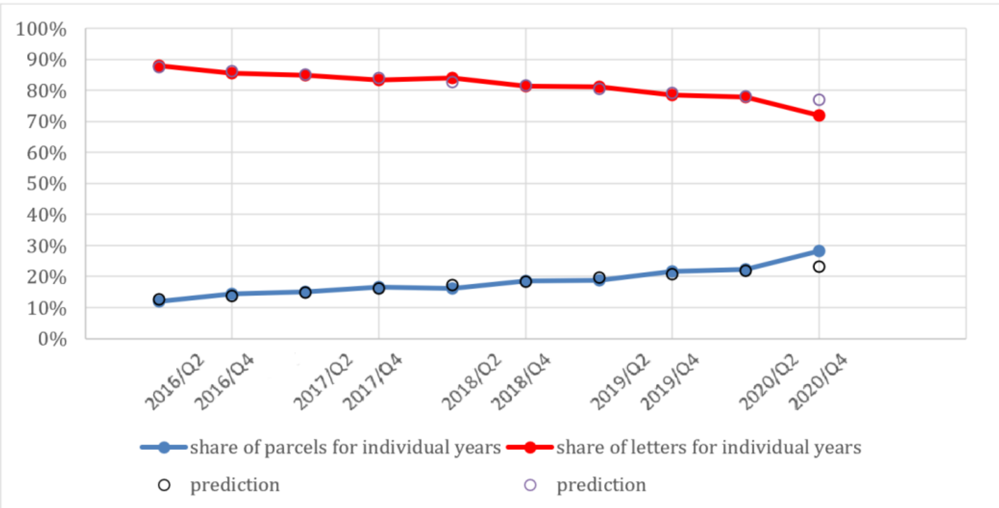

Figure 3. The number of submitted packages in Slovakia from 2016 to 2020. *Source: [17].*

The regression of the dependence of the proportion of letters and/or parcels over time is shown in Table 1. The last two values, which were reached during the COVID-19 pandemic, were omitted from the regression model. And so, the model is created from eight values of the pre-pandemic period, while it is used to predict values during the pandemic (Table 2). These predicted values are compared with reality, and the difference is calculated as the impact of the pandemic. The primary aim of Slovak Post was the letter delivery by means of more than 1 400 post offices. Sheet sorting lines are set to capacities that have not been used for many years. At the same time, with the annual drop in letter shipments, Slovak Post recorded growth in the number of letter items that are unsuitable for machine processing and must therefore be processed manually, which, of course, increases labour and human capital costs.

On the other hand, the parcel sorting lines Slovak Post uses (in Bratislava, Žilina, Zvolen and Košice) are technologically behind their zenith, and their capacity is insufficient. The last mile carrier shapes customer satisfaction. The problem with parcel delivery is the delivery network, which is separated from the letter mail

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network. Parcel shipments travel after sorting to the so-called any of the nearly seventy regional nodes. Carriers then take them directly to the addressee, while part goes now to the post office (if the package is addressed to the post office). The Slovak Post, therefore, has two separate worlds: in one, which is less busy from year to year, there is a network of mail carriers who bring letters to the addressees every day, and in addition, the post office also has a network of increasingly busy carrier delivery, in which up to 95% work external carriers. As a result, a mail carrier with a letter shipment and a carrier with a parcel shipment can come to the same address on the same day. Of course, Slovak Post does not consider this method effective and is already starting to change it. However, another crucial problem that Slovak Post faces is the quality of the delivery network, especially the range of options for receiving parcels by the addressee and the quality of the customer experience from the delivery process itself.

Currently, among the 4 480 mail carriers, only 554 are motorised. These are usually rural areas where the mail carrier has a motor vehicle at his disposal. By streamlining and re-allocating cars from administrative employees, the Slovak Post has motorised more than 50 districts and plans to increase their number to 570. Motorised districts represent a potential for at least partial unification of the delivery of parcels on the last mile, thus saving financial resources. Motorisation also brings savings because the width of the serviced area is reassessed with each new motorisation. The districts are getting bigger; for example, three pedestrian districts with three mail carriers will become two motorised districts with two mail carriers. Considering the boom in e-commerce in recent years and long-term global trends that will direct buyers more and more to the Internet, it is also necessary for Slovak Post to build a network of delivery points across Slovakia that will provide customers with convenient options for picking up parcels.

Slovak Post has already built a primary network of 144 parcel boxes, which it plans to expand by nearly three hundred more in the coming years. However, it does not intend to go into its extensive network of parcel boxes as a competitor, because, according to its experience, it would not be profitable. It will focus on building boxes with the most significant potential based on the population's purchasing power, population concentration, and the history of the development of parcel delivery volumes. Also, the new generation of boxes it plans to procure should bring a higher standard of user comfort, simplified control and, finally, a much lower purchase price. A separate development area is the concept of low-capacity 10 to 12 mailboxes developed in cooperation with selected partners. The goal is to install this type of box in cooperation with the local government, especially in municipalities where Slovak Post never had a branch or has cancelled it. The boxes should be used to pick up undelivered express items and notify registered and undelivered items of the universal service (except for official items) via PIN. However, this requires an amendment to the legislation. In this way, the main disadvantage of the absence of a brick-and-mortar branch in the village could be eliminated, and thus the need to pick up an undelivered registered parcel at the successor post office in the next village.

The so-called package to the address is probably the most frustrating carrier delivery. The customer does not know precisely when the carrier will call during the day, so it is more complicated to collect the shipment at the address. Slovak Post is developing a new customer environment with its partners, which should dramatically improve this experience. Through GPS localisation and dynamic tracking, the application should provide clients with more accurate information about the delivery time of the shipment, including the location of their carrier and the remaining time until delivery, which will be updated based on the development of the delivery situation. The situation was like parcel delivery and food delivery during the COVID-19 pandemic. In 2022, research to determine the use of online food shopping and the reason for consumers' food purchases through a shopping portal was conducted in Slovakia. The survey found out that as many as 47.9% of respondents who purchase food through online shopping portals only started to do so with the emergence of the COVID-19 pandemic [17,22].

For the 46.4% of respondents who were already buying food online before the pandemic, the frequency of purchases increased with the emergence of the pandemic. 47.8% of respondents from the category of regular shoppers, who placed orders before the onset of the COVID-19 pandemic, assessed that their shopping frequency remained the same. Food supply, restaurants and prices for food and services have increased. Respondents reported that they could not physically go directly to the restaurant, were not at risk of contracting COVID-19, and were in quarantine as reasons why they started placing their orders after the start of the COVID-19 pandemic. Conversely, using plastic packaging for food delivery is also why respondents do not purchase food through shopping portals [19,23]. "Consumers are aware that every effort should be made to prevent the world from drowning in plastic waste. Society is, in general, open to the use of bioplastics produced from the second-generation resource if second-generation bioplastics contribute to environmental and pollution reduction targets" [21].

Table 1. The regression of the dependence of the proportion of letters and/or parcels over time. *Source: [9–11,17].*

Strengths	df	SS	MS	F	Significance F
Regression	1	0.0058	0.0058	87.1495	8.5614E-05
Residual	6	0.0004	6.6125E-05		
Total	7	0.0062			
Intercept		Coefficients	Standard Error	t Stat	P-value
Time		0.1136	0.0063	17.9293	1.9357E-06
Intercept		0.0117	0.0013	9.3354	8.5614E-05

Table 2. Regression statistics (summary output). *Source: [9, 10, 11, 18]*

Regression statistics	
Multiple R	0.9673
R Square	0.9356
Adjusted R Square	0.9249
Standard Error	0.0081
Observations	8

Impact

The necessity of analysing the CEP market after the COVID-19 pandemic is nowadays highlighted by the changes that have occurred after 2019. Such changes have affected every partial market from the economic, societal, and technical view. It is essential to realise that such analysis is crucial for the Slovak Post and its position in Slovakia and for any other postal company. We aimed to compare the situation in Slovakia and the EU and, at the same time, present relevant numerical indicators, and graphs. To conclude, it is not possible to react flexibly to the changes caused by the COVID-19 pandemic, and that is why the CEP market will be able to recover only after a significant modernisation. Otherwise, the e-commerce market with alternative carriers would change the CEP market once and forever. The facts mentioned above are clearly described and analysed precisely in this paper.

Conclusions

Continuous growth in global parcel volume is expected to resume by 2026, reaching approximately 262 billion parcels. In that case, the transport volume will increase almost sevenfold in 13 years. Europe's express and small package market is estimated to reach more than 77 billion EUR in expected revenue in 2020. Some markets are much more progressive compared to countries. In 2019, the German CEP market was the largest in Europe and processed almost three billion parcels. This parcel-handling volume made the German CEP market five times larger than the second largest, the Italian CEP market [1].

Slovak Post recorded a substantial decrease in revenues, due to the COVID-19 pandemic, which fell by almost 11 million EUR to 339.4 million EUR due to restrictions on the international exchange of goods, which led to a decrease in the number of incoming shipments, which caused a reduction in revenues from international postal traffic by seven million EUR. Revenues from universal postal services and contractual letter shipments in domestic traffic decreased by 3.4 million EUR and revenues from postal payments decreased by two million EUR. At the same time, the loss of services for the payment of pensions and state social benefits provided for the state in the amount of more than six million EUR contributed to the deepening of the loss. On the other hand, the epidemiological situation caused an increased demand from the population for the delivery of express packages for contractual partners (e-shops) during restrictions on the operation of brick-and-mortar stores, which positively affected Slovak Post's revenues from express services. However, these could not fully compensate for the already-mentioned revenue shortfalls [15]. Slovak Post's sales fell by around 10 million EUR mainly due to the second wave of the COVID-19 pandemic. The most affected in recent months were revenues from international postal traffic, which decreased by six million EUR. Payments for universal services also fell by four million EUR. The increased number of sick employees due to COVID-19 affects the operation of post offices and logistics. This was reflected in restrictions on opening hours for the public as well as delivery times. In the most critical situations, when the entire post office team goes down at once, and it is impossible to replace it immediately, the post offices must be closed for the necessary time [24].

Conflict of interest

There are no conflicts to declare.

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EPC^{HC}- ENERGY PERFORMANCE CONTRACTING (EPC) MODEL FOR HISTORIC CITY CENTRES

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Highlights

- funding model for energy retrofitting projects in historic urban areas of cultural heritage importance
- analysis and recommendations for approaching urban historic districts with EPC
- The EPC model which encompasses multi-stakeholder approaches and cultural heritage preservation at the district level

Abstract
The current predominant obstacle for the implementation of energy retrofitting projects at the neighbourhood level is attributable to restricted funding options, which is especially relevant for the expensive renovation of buildings of cultural heritage importance. The first aim of the article is to articulate and identify the main characteristics which influence the funding processes for energy retrofitting historic urban districts. The second objective is to build a comprehensive approach/procedural funding model based on these identified specifics/characteristics. The "energy performance contracting model for historical city centres" (EPC^{HC}) is constructed with procedural processes (steps) associated with the main specific characteristics of urban central districts. The principal attributes which define and influence EPC in historical city centres are "district-level retrofitting", the "multi-stakeholder approach" and "cultural heritage preservation". First demonstrated are the benefits of the district level EPC's "economy of scale". Secondly, city centres are specific neighbourhoods with several public (municipal, governmental) and private entities, necessitating a particular tailor-made EPC approach is necessary for each stakeholder. Thirdly, the article focuses on the issue of higher retrofitting costs because as a result of historical building status and finding an optimal solution to overcome the conflict between sustainable renovation and cultural preservation. The procedural model for EPC^{HC} in historical city centres offers step-by-step guidelines with suggestions to be followed in order to approach and involve all the various stakeholders. EPC^{HC} could open a new perspective on district green retrofitting and could facilitate municipalities' decision-making processes upon deciding to retrofit historical central districts.

Keywords
EPC; energy performance contracting; historical city centres; multi-stakeholders; cultural heritage preservation; district energy retrofitting; procedural funding model.

Introduction

Conservation, renovation and the revitalisation of buildings' cultural heritage represents a font of community empowerment and can also generate economic benefit [1]. Historic city centres can be considered heritage assets, or economic goods which have significant, immeasurable cultural value and are irreplaceable [2]. Planning for sustainable urban restoration of urban city centres should incorporate policies aimed at preserving the unique characteristics of historic urban areas and at stimulating their functionality for contemporary urban purposes, such as housing and commercial activities [3].

The process of the sustainable urban renovation of historical city centres is a complex matter that should be approached from several different perspectives involving environmental, social and economic dimensions [4]. There should be a holistic approach, taking into consideration the built environment and the social structure of the local community; conjoining the approach of the energy efficient refurbishment of residential buildings with integrated urban development concepts, the modernisation of the energy infrastructure, and the identification of innovative financing instruments [5]. Buildings represent 40% of the EU overall energy consumption [6], and as such the recent EU "Renovation Wave Strategy" target is to double the yearly energy renovation rates

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in the next decade, and explicitly underline the necessity of developing neighbourhood-based approaches with integrated renewable solutions [7]. Consequently, it is crucial to create new holistic energy renovation methods and systems. Some relevant studies [8,9] have focused on the development of a simplified holistic sustainability decision-making support framework and a holistic multi-methodology, which includes the involvement of different stakeholders. However, there is need for further studies focusing on the retrofitting of urban districts.

Currently, the prevailing barriers to the implementation of effective energy saving measures on large buildings stock with historic relevance are attributable to the limited funding for an extensive and costly retrofit. Limited time and money exclude the possibility of conducting a detailed analysis on all retrofitting solutions. Local administrations often cite these difficulties as reasons why they are unable to intervene [10]. The article focuses on defining the appropriate funding model for energy retrofitting projects in historic urban areas of cultural heritage importance. The first aim of the article is to articulate and identify the main specific characteristics which influence the funding processes for energy retrofitting historic urban districts (* the use of the term "districts" is meant to be understood as a synonym for "neighbourhoods" and does not imply any administrative connotation). The second objective is to build a comprehensive approach/procedural funding model based on these identified relevant specifics/characteristics.

Research background and methodology

Historic districts (which are often situated in city centres) symbolise the heart of each city and at the same time represent dynamic and complex neighbourhoods with unique specificities. Historic city centres usually include several different public and private stakeholders [11,12] and are generally very difficult to energy retrofit due to the age of the buildings and the fact that they are protected by cultural heritage status [13,14]. Several studies have identified a "conflict relationship" between the degree of sustainable retrofitting and cultural heritage preservation [15,16]. The complexity of energy retrofitting derives from two main aspects which define historic urban districts: (1) multi-stakeholder ownership (multiple public and private owners) and (2) higher refurbishment costs for cultural heritage preservation where it is necessary to strike a balance between sustainable renovation and preserving cultural integrity.

Streimikiene and Balezentis [17] identified several barrier categories for large scale (district) energy renovation: economic/financial barriers (ratio of investment cost to value of energy savings); hidden costs (cost or risks that are not captured directly in financial flows); market failures (market structures and constraints that prevent a consistent trade-off between specific EE investment and energy saving benefits); behavioural and organisational barriers (behavioural characteristics of individuals and companies that hinder the implementation of energy efficiency technologies and practices); information barriers (lack of information provided on the energy saving potentials of large scale energy renovation); political and structural barriers (structural characteristics of political, economic, energy systems which make efficiency investment difficult). Jowkar et al. [18] as well as identified several barriers for sustainable building renovation such as long-term payback period, a lack of information about its economic and social benefits, knowledge of how to engage and become involved as well as personal benefits (regarding better indoor quality or reduced energy costs); and pointed out that the most significant barrier is the high investment cost. When undertaking the renovation of multiple buildings in a neighbourhood, financial barriers can obstruct energy refurbishment [19]. Funding the implementation of sustainable energy measures remains one of the major challenges on the path towards sustainable energy communities. Barriers also include high initial costs for the development of sustainable energy projects, as well as low profitability for certain developments, even though these projects may bring a great number of socio-economic benefits [5].

Financing the sustainable (energy) renovation of city districts such as historical city centres is quite complicated as it is difficult to calculate and anticipate all the possible (un)predictable risks. The main financial challenges that could obstruct green retrofitting (urban) projects are [20] a perception of substantial risk when investing in innovative solutions and energy efficiency measures, undefined energy price policies and uncertainty about fossil fuel prices, the large volumes of investment required, long-term delays before reaching maturity/profitability, limited capacity for public funding (high public deficits in municipalities and an inability to raise funding from capital markets). As previously mentioned, the main identified challenge to retrofitting large and complex districts such as historical central neighbourhoods is the "funding problem". Despite political

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commitment at the local level, these projects are often not realised by municipalities due to an absence of financial resources and/or a lack of capability in applying complex financing mechanisms. Usually, municipalities and other local stakeholders do not possess enough economic assets to retrofit the entire district, especially complex districts comprised of several buildings under cultural heritage protection, which are more difficult and expensive to retrofit. Energy performance contracting (EPC) for district retrofitting seems to be a feasible funding solution, especially when stakeholders (private individuals, companies, public entities) do not possess adequate financial resources. The main driving force behind adopting EPC is that the energy retrofit would be completely free for all the contractors (there are no investment costs).

In the extensive study by Boza-Kiss et al. [21] regarding EPC performance it was noticed that the average EPC market within the EU has been on a constant rise in the last decades. The rise was noticed also in the EPC's traditionally ignored sectors, such as residential and SMEs. EPC at the district level is "already happening" and it is effective. However, EPC is very rarely applied/introduced to the central zones of cities, in part due to the complexity of such areas (as previously mentioned - issues with multiple stakeholders and cultural heritage preservation). The main research objective of the article is to identify "the adequate model/process to approach historic city districts with the energy performance contracting (EPC) funding scheme". The article proposes a procedural funding scheme which could connect all the involved public and private stakeholders in city centres to achieve a common goal. The article will further examine why the EPC funding scheme is one of the most appropriate funding schemes for urban historical districts. In addition, all the benefits that the EPC funding instrument could bring to a historic district's stakeholders will be highlighted.

Based on a comprehensive interdisciplinary literature review, analysis of different EPC guidelines, best-case analysis will be shown and explained, as well as the distinguishing characteristics of retrofitting historical urban districts. These findings will also be relevant for the "SWOT analysis for EPC implementation processes in historical urban districts" and especially for the innovative matrix of EPC processes (steps) that could be considered when EPC is performed in historical districts. The operational model for EPC implementation in cities' historical central districts (EPC^{HC}) combines the main characteristics/features/processes of the EPC funding scheme by encompassing/taking into consideration the main characteristics/attributes of historical urban districts. EPC^{HC} combines the theoretical and practical framework related to the cultural heritage preservation of buildings inspired by the Troi and Bastian [16] with "traditional" EPC processes partly based on the Transparency Guide [22]. In addition, the EPC^{HC} operational model is constructed with procedural processes (steps) associated with the main specific characteristics of city central districts with different suggested approaches for different stakeholder groups**.** EPC^{HC} could facilitate municipalities' decision-making processes upon deciding to retrofit historical central districts. The research approach is focused on historical city centres, but the final matrix could also be applied to other historical districts which are home to edifices which have been granted cultural heritage status. The main difference is that city centres usually have a higher concentration of municipal, regional and governmental buildings (especially in capital cities), which affects the whole EPC implementation process.

Results and discussion

<u>EPC - funding option for district energy retrofitting</u>

To surpass financial challenges (especially in relation to limited public funding) it is necessary to analyse all the financial instruments that could facilitate the implementation of green retrofitting interventions. There are several innovative financing mechanisms that can be utilised for urban renovation, for example [20,23] project financing, smart bonds, spread shareholding, crowd-financing, energy performance contracting for energy efficiency (EPC), etc. In their study, Bertoldi et al. [24] identified 13 financial instruments for energy renovations in buildings (according to the level of market saturation), of which three were classified as "traditional and well-established" (grants and subsidies, tax incentives, loans), three as "tested and growing" (energy efficiency obligations, energy services agreement (ESA), energy performance contracting) and seven as "new and innovative" (on-bill finance (OBF), property assessed clean energy (PACE) financing, energy efficient mortgages, energy efficiency feed in tariffs, incremental property taxation, one-stop shops, crowdfunding). In recent decades, EPC has emerged as a form of 'creative financing' for capital improvement which allows funding energy upgrades from cost reductions. Under an EPC arrangement, an external organisation (typically an energy service company - ESCO) implements an energy efficiency project or a renewable energy project and uses the stream of income from the cost savings to repay the costs of the project, including the investment costs [25].

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According to the EU Energy Efficiency Directive 2012/27/EU (EED), Energy Performance Contracting "means a contractual arrangement between the beneficiary and the provider of an energy efficiency improvement measure, verified and monitored for the entirety of the contract, where investments (work, supply or service) in that measure are paid for in relation to a contractually agreed level of energy efficiency improvement or other agreed energy performance criterion, such as financial savings" [26]. The contract between ESCO and the building owner(s) contains guarantees for cost savings and takes over the financial and technical risks involved in the implementation and operation for the entire duration of the project, typically 5 to 15 years [5]. Energy Performance Contracting (EPC) can provide substantial energy savings for building owners using the principle of repaying the energy efficiency investments directly from the saved energy costs [22].

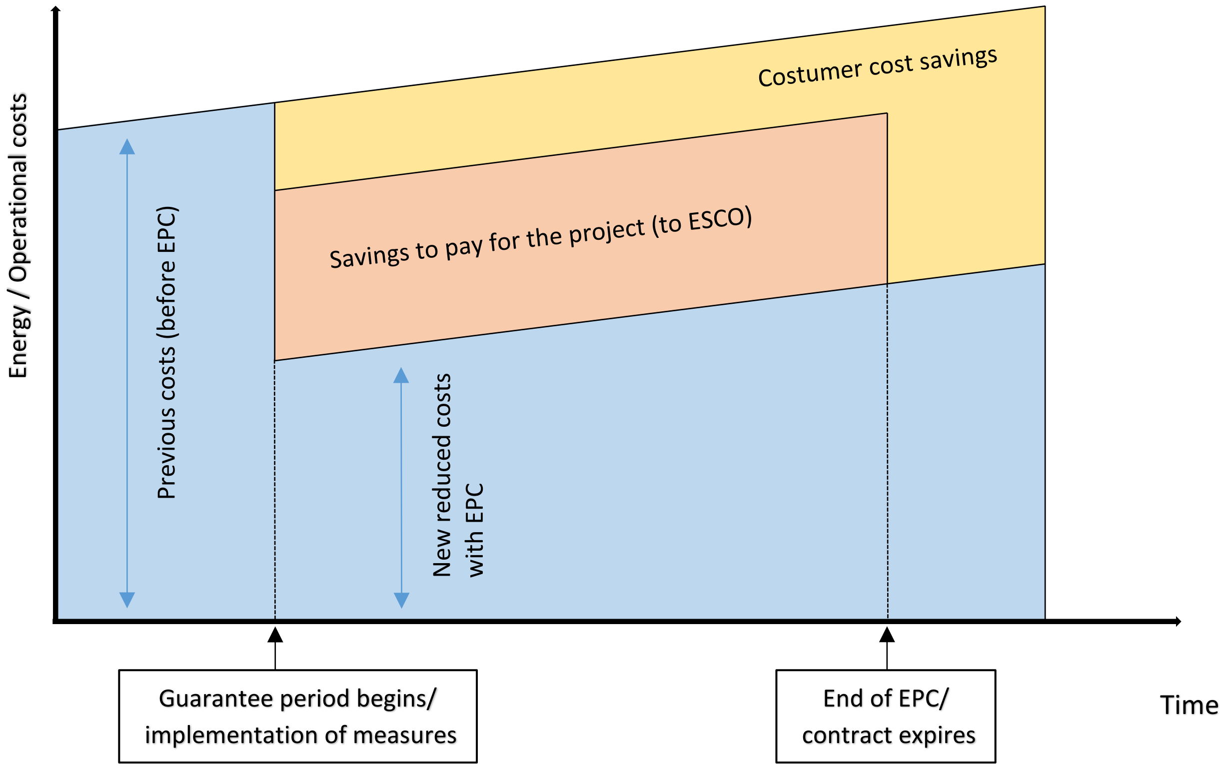

Figure 1. Energy Performance Contracting (EPC). *Source: Transparense.eu [22].*

In their analysis of EPC stakeholders' interviews, Davies and Chan [27] identified the most common perceived benefits of EPC, namely energy cost savings, guaranteed results and savings, and the elimination of up-front capital. Within the same research study, they also identified the most commonly encountered barriers/problem of EPCs, which are setting up and agreeing upon an energy baseline, mistrust, and a lack of commitment. This implies that is advisable to opt for an experienced energy savings company in which the stakeholders may have confidence. Bertoldi et al. [24] highlighted that the main advantages of EPC are no upfront costs for consumers and knowledge of ESCOs; the main challenges of EPC are performance risk and the high fees charged by ESCOs.

Approaching urban historic districts with EPC (analysis and recommendations)

In this section, the main attributes of historical city centres (district level retrofitting, multi-stakeholder approach, cultural heritage preservation) which determine and influence EPC implementation are first explained. Acknowledging these key determinant aspects is fundamental in order to establish the EPC^{HC} model which might facilitate the expansion of EPC funding typology in urban centres.

The complexity of retrofitting historical city centres

There are two main differences in the EPC procedural model between an "ordinary district" and a historical urban centre. Historical urban centres are characterised by (1) multi-stakeholder (public and private) ownership; (2) higher retrofitting costs because of historic building preservation. The subsequent subchapter will deepen the analysis of these two aspects which are crucial to determine the specific processes of retrofitting historical neighbourhoods. However, it is above all necessary to point out what the benefits of neighbourhood level (multi-block) energy retrofitting with EPC are in comparison to the retrofitting of a single building.

- Benefits of district energy retrofitting with EPC.

EPC projects deal with numerous uncertainties such as energy price oscillations, uncertain future energy consumption of the buildings, and unpredictable investment costs [28]. Several aspects influence the fulfilment of projected energy savings, e.g. quality of system operation and maintenance, environmental conditions, accurateness of predicted savings, etc. [29]. With EPC district-level retrofitting it is possible to overcome these issues by achieving the benefits of the economy of scale and diminishing the risks related to a single building's erroneous energy restoration audit. This is particularly true for historical urban neighbourhoods, where each building is unique and the mentioned risks are higher, and it is therefore advisable to intervene on a larger scale rather than on individual units [10]. Restoration at the district scale is defined as the contemporaneous renovation of several buildings situated in the same district to achieve common benefits such as cost savings, cost-effective funding advantages, effective use of renewable energy sources, etc. [30]. It is possible to save a considerable number of financial resources in several areas such as procurement of energy analyses and construction due to the "economy of scale" - achievable with the refurbishment of several buildings at the same time. In addition, it is possible to employ renewable energy sources more efficiently for local heating, cooling and electricity production when the local energy systems supply several buildings instead of one single building [31]. In comparison with the district refurbishment, single building EPC retrofitting projects are usually too small and cost savings do not always compensate for all the administrative work [12]. Efficient EPC management requires a neighbourhood-level approach [31]. Apart from the recognisable benefits of district level retrofitting there are also some barriers. Häkkinen et al. [30] identify the three most important barriers related to district level EPC, which are (1) the presence and collective agreement of several building owners to start district-level retrofitting projects, (2) absence of an initiator/activator/facilitator to initiate district-scale projects and (3) institutional and legal barriers associated with urban planning.

- Multi-stakeholder ownership with public and private entities

Historic city centres are very specific and unique neighbourhoods as they encompass several distinct stakeholders (commercial, governmental, municipal, and residential) and because most of the main public/civic buildings are usually concentrated in a city centre. EPC could be performed in city centres with the cooperation/involvement of all the above-mentioned stakeholders (from commercial - industrial buildings to residential buildings, covering single houses/single buildings and blocks with multiple owners). There are good examples of multi-block/building regeneration with EPC, especially for urban agglomeration where there is one individual entity which owns several units (e.g., a social-housing neighbourhood where the proprietor is the municipality). Single ownership simplifies the drafting of an EPC contract and consequently the renovation of the buildings. Le Gentil [12] points out that in the case of multiple privately owned buildings it is very complicated to draft the EPC contract with each owner. One of the main challenges of district-scale energy refurbishment is the necessity to involve several actors/stakeholders in the value chain. It is rare for all residents to share the same values, and this can affect urban development. As private occupants tend to base their decisions on financial issues and short-term preferences, the role of a public partner in the partnership is vital [11]. Several municipal and state buildings owned by (one) public stakeholder are usually situated in historic centres. The publicly owned buildings are usually municipal offices, parliament, ministries, government institutions, hospitals, nurseries, public elementary and high schools, universities, etc. The high concentration of public ownership (which in theory represents a mono-ownership typology with one stakeholder) in historic centres represents a significant advantage in the EPC renovation process. The public sector (in the EU) has, in general, a positive attitude towards EPC. In Germany, for example, 95% of all the EPC clients are public authorities and hospitals [32]. The municipality of Paris has used EPC to retrofit more than 600 public schools [33] and in Milan, 98 public buildings were renovated with just one EPC tender by the Covenant of Mayor [34]. One of the most famous and massive urban regeneration/retrofitting with EPC was done in Berlin through the municipality program called "Energy Saving Partnership". Within this special partnership more than 1400 buildings in Berlin have been refurbished [32]. These examples confirm that it seems less complicated to apply the EPC funding scheme to public buildings.

- The complexity and higher costs of retrofitting buildings with cultural heritage significance.

It can be argued that a vital component of sustainable urban development is the preservation of cultural

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and natural heritage [13]. When aiming to reduce the environmental impact of historical building stock, special attention is required in relation to the conservation of heritage status[14]. While protecting the cultural heritage of historical buildings is essential for local community development, the protection of natural resources is important for the citizens' well-being and for long-term environmental sustainability. Heritage management includes edifices, sites, and other assets of historical, cultural, political, artistic, and/or religious importance in addition to community-related cultures, skills, knowledge, and traditions which should be preserved for future generations [13].

The historic building stock is heterogeneous and comprises constructions from different time periods, created with various techniques and building materials. These demands differentiate energy retrofitting strategies in historic districts to balance energy and building conservation. Consequently, better knowledge about the specificity of the historic building stock is needed [35]. For example, an energy audit for historic buildings requires an understanding of original construction methods, heritage principles, changes that have been made over time, performances, possible threats, and retrofitting solutions. This knowledge is essential to avoid possible pathologies and physical damage which can be achieved using non-destructive technologies (NDT) that should be applied in historic urban areas [36]. In addition, the renovation of historic constructions is understood to be a cultural risk, and public legislation usually restricts the modification of the heritage building stock [6]. Consequentially, there are some fundamental aspects related to cultural heritage preservation that should be considered when retrofitting historic centres. First, each unique historic building needs its own tailor-made set of solutions which respect its cultural heritage specificities. Consequently, the investment effort will usually be greater in comparison to the "standard" retrofitting.

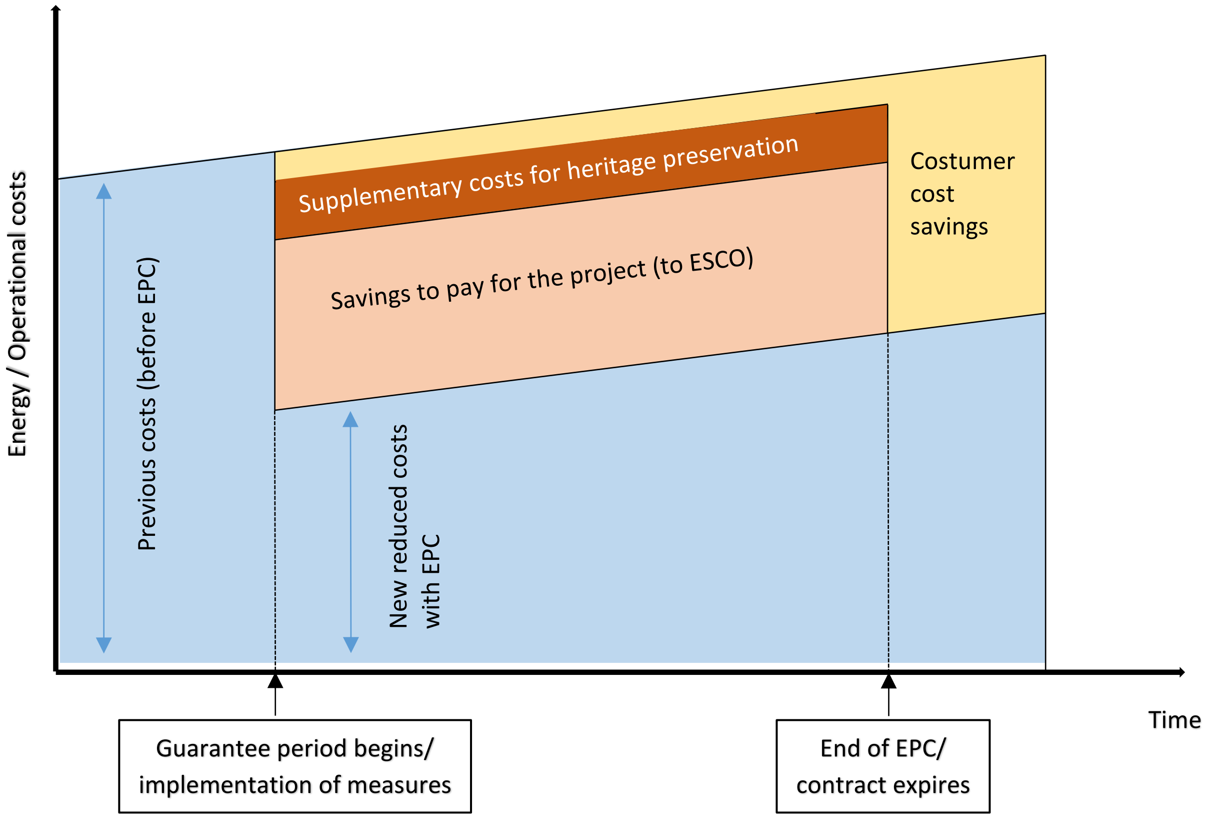

Figure 2. Supplementary investment costs for the heritage preservation of buildings in EPC projects. *Source: Author.*

Because of the supplementary investment costs for heritage preservation, the savings are lower in comparison with a "typical" EPC investment (see Figure 2). This could potentially render the EPC investment less attractive to building owners. However, even with the extra costs the owners would still profit from the investment (lower monthly costs, retrofitted building, better aesthetics, higher property values, etc.). Secondly, historic buildings which undergo an energy retrofit that respects their cultural value will not reach the equivalent efficiency levels in comparison with highly efficient new buildings [16]. These two arguments show a conflict between

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implementing energy efficiency measures and the preservation of buildings as “heritage” [14,15]. Conservation experts are often concerned that the application of energy efficiency measures could compromise the heritage value of historic constructions. On the other hand, energy consultants complain about overly restrictive building conservation authorities obstructing energy efficiency improvements. (Over)protecting urban heritage could cause local antagonism to urban development, while urban development is at times thought to threaten cultural heritage assets. The main challenge is how to find adequate compromises between the qualitative benefit (heritage significance) and quantitative benefit (environmental sustainability) [14].
Improving the energy performance of historic urban areas signifies finding a balance between heritage significance and energy efficiency measures [37]. Troi and Bastian [16] identified a frequent lack of interdisciplinary communication/cooperation between various specialised authorities. All these challenges could be overcome with proper planning, clear communication and mixed interdisciplinary teams. Energy retrofitting should be considered a tool for protecting cultural heritage rather than a process that generates conflicts [38].
It is advisable that the ESCO (within EPC projects) should not be alone in financing the entire energy retrofitting interventions of cultural heritage buildings, for which the costs for pre-design (prior analysis and diagnostic costs), and construction costs (particular techniques to safeguard the heritage characteristics) are particularly elevated [39]. In order to cover the extra/additional costs for cultural heritage preservation, there should/might also be available some targeted national/transnational funds such as municipal subsidies, governmental subsidies, EU funds, etc. The role of governments and transnational entities could be essential in order not to negotiate and divide these additional costs between the investors and the ESCOs. In addition, Filippi [39] suggests that it is necessary to make use of “off-balancing sheet financing” for the green retrofitting of such buildings, such as joint ventures, research and development partnerships or operating leases.

- SWOT analysis

Table 1. SWOT analysis for the EPC implementation processes in historical urban districts. *Source: Author.*

Strengths	**Weaknesses**
▪ large project (district), with several building units, which diminishes the EPC administrative costs and at the same time diminishes the investment/ return risks. ▪ several public buildings owned by a single entity (municipality or state) ▪ buildings are situated and concentrated within one neighbourhood - the city centre, which makes the introduction of EPC easier ▪ historical urban districts are “privileged districts” - places of interest; the public authority is motivated to retrofit the main representative and tourist destinations	▪ protecting the cultural heritage of buildings in the retrofitting process lowers the efficiency level of the energy retrofit ▪ higher investment costs as a result of cultural heritage preservation of the refurbished buildings ▪ multi-ownership of the district - multi-stakeholders of public private buildings (residential, commercial, government, municipal) complicate the EPC process
Opportunities	**Threats**
▪ improvement of the urban (environmental) sustainability of the area (lower environmental impact) ▪ increasing the (touristic) attractiveness of the urban area which could consequently generate more jobs, services, etc. ▪ increase the price/value of properties (which on the other hand could also be understood as a threat if it leads to destructive gentrification) ▪ increase in the quality of life for the residents (better homes/domestic environment)	▪ new EU/state/municipal legislation that could change the district policies. ▪ bankruptcy of the ESCO ▪ inadequately executed refurbishment; the predicted energy retrofit efficiency would be below predicted standards. ▪ because of the higher prices of the buildings (after the retrofit) it could raise the rent; risk of gentrification ▪ possible conflicts between the municipal and regional/state authorities

Based on the three main distinguishing characteristics which highlight the complexity of energy retrofitting historical urban districts with EPC, a comprehensive SWOT analysis was done (see Table 1). The SWOT analysis emphasises the main identified weaknesses, strengths, threats and opportunities of the EPC implementation processes for historical central districts. The energy performance contracting model for historic city centres (EPC^{HC}) will be presented in the next section, taking into consideration all the specifics of the EPC funding instrument and all the mentioned characteristics, barriers and facilitators in relation to retrofitting historic districts. EPC^{HC} introduces a novel approach for green retrofitting historic centres and at the same time could facilitate the future introduction and expansion of EPC in historic urban districts.

EPC^{HC} – operational model for EPC implementation in cities' historical central districts

In city centres there are usually three main stakeholder groups/typologies of building owners: public institutions (single ownership), private residential owners (rarely single ownership, generally multi-ownership of a building) and private commercial owners (single and multi-ownership). Among the owners and the implementer (ESCO), and with the possible collaboration of an "external" subject, the first question that arises is "who will be the initiator of the EPC process in a historical urban district"? There should be someone who would connect all the different entities, organise collaboration/networks and seek commitment from the different owners. It is crucial to define 'who' among the various stakeholders can be the most adequate 'activator' to initiate district-scale refurbishment projects. Another question which follows is "who will pay the activator?" National/federal/transnational incentives or subsidies are essential to compensate the expenses of the activator who would invite, assemble and manage the entire stakeholder group and organise a preliminary analysis for retrofitting possibilities for all the potential buildings in the selected area [30].

Häkkinen et al. [30] pointed out that when the activator comes from a private company, potential customers - especially flat owners - may be mistrustful. Therefore, the participation of the municipality at the beginning is essential to bring neutrality to the process. It is suggested that the municipality should take the role of initiator in the EPC process in the first phase, and the role of facilitator in order to provide constant support and collaborate with the entire stakeholder group (local owners, contractors and others). The municipality should create a special "urban facility management unit" (UFMU), which would take responsibility for the entire governance and management of the EPC project. UFMUs function as an "intermediator" which connects communities, municipalities and ESCO companies and interrelates various public and private sectors. The main functions of the UFMU are informing, consulting, involving, connecting and empowering different stakeholders within the EPC project [18].

The role of the UFMU is to expand the field of facility management from the particular organisation context to the complex urban context supporting new collaborations and encompassing urban community necessities [18]. In addition, as mentioned before, it has been shown that single ownership simplifies the drafting of a contract for the renovation of flats and that the high prevalence/concentration of publicly owned buildings in historic centres is beneficial for EPC implementation and represents a significant advantage. From these arguments it is evident that the most effective way to start the process of EPC implementation in historic centres is with public institutions. For the very first step of the innovative procedural EPC^{HC} scheme, it is suggested that the municipality (through the UFMU) takes the role of initiator and together with other public institutions present in the central district (provincial, regional, governmental institutions) should create a common special project-related public entity –a "local EPC public consortium" (see Step 1 in Figure 3).

This newly formed public entity would agglomerate and represent all the public buildings of the selected city central area (public schools, hospitals, ministry buildings, municipal buildings, and all other buildings owned by the state, region or city). In that way, it is also possible to encompass a critical number of buildings which consolidates the economic feasibility of the EPC project. In the second phase, the newly formed public entity should engage in public debate with other local stakeholders and promote the positive benefits of EPC through leaflets, brochures, media announcements and especially through local workshops with local residents/owners. The newly created public consortium should invite all private owners (commercial, residential) in the district to join the district EPC retrofit of their buildings. This "absolutely free" offer would be addressed to every building owner of the selected central urban area. The public consortium (lead by the municipality's UFMU) should be responsible for all the administrative issues related to the EPC processes. However, the confirmation to join the EPC project is primarily expected from buildings owned by mono-owners (especially commercial centres or other large real estate owners). Although they would be more than welcome, it is possible to predict that not all the private entities would join in for the first round of the EPC project. It is much more complicated to approach multi-flat/multi-family buildings as just one rejection from an apartment owner could stop the EPC process for the entire building. It is therefore essential to communicate/present the complete process adequately and sensibly to all private owners and to address all the benefits of energy retrofitting that they could benefit from with no investment costs (lower bills, the improvement of building quality and an increase in the value of the building).

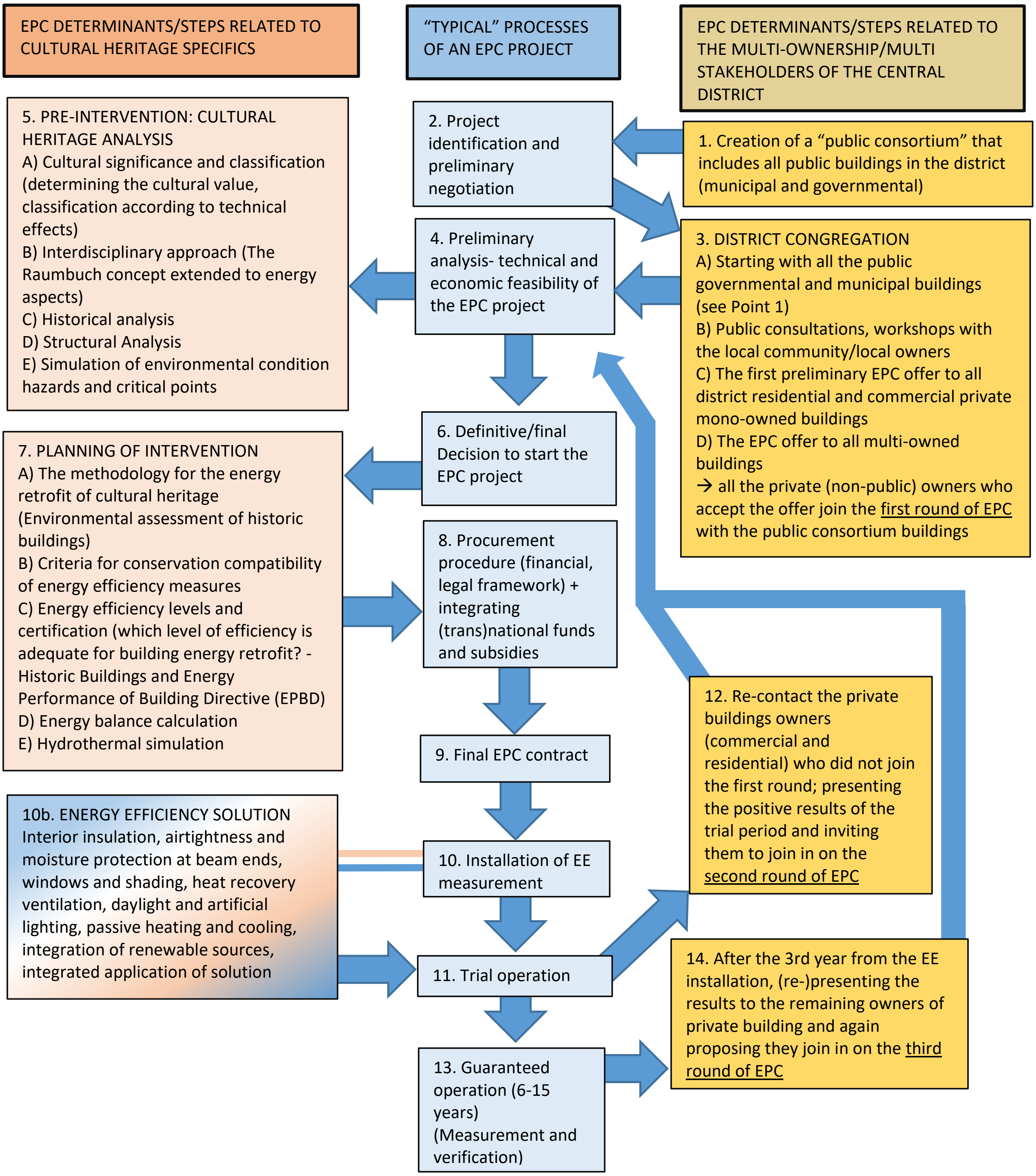

Figure 3. EPC processes for historical city centres (EPC^{HC}). *Source: Author.*

After clustering all the public and (hopefully as many as possible) private building owners, the next steps follow - the preliminary analysis for the technical and economic feasibility (see Step 4, Figure 3) and the especially important “pre-intervention cultural heritage analysis” (see Step 5). Pre-intervention cultural heritage analysis is an added process to “traditional EPC practices”. At this point, it is essential to understand and carefully estimate the costs of the intervention.

If the preliminary technical and economic analyses confirm the feasibility of the project and if the cultural heritage pre-intervention analysis confirms its overall achievability, all the involved stakeholders of the central district can eventually accept the definite decision to implement EPC for the selected buildings within the district (Step 6, Figure 3). After the green light for the project, what follows is the creation of a concrete and detailed intervention plan that should consider the energy efficiency levels and the environmental assessment of the historical buildings. At the same time, it is required to start financial and legal procedures between the beneficiaries and the selected ESCO which would perform the district retrofit. If all the parties involved agree with the terms and conditions, they sign the final EPC contract and the ESCO could start the energy efficiency installation with the implementation of specific energy efficiency solutions for historic buildings (Steps 10 and 10b, Figure 3).

A final energy audit after the termination of the energy retrofitting could provide personalized information about the achieved energy reduction. Within the EPC^{HC} the use of special “feedback systems” is recommended which represent particularly prominent features within EPC projects. Exemplary feedback solution are smart meters and other building-monitoring systems, which follow the energy consumption for electricity, heating, cooling, and the usage of hot water [17,40].

Some months after the energy retrofit is concluded, when the results of energy reduction and the improved quality of life in the refurbished buildings are clearly visible, it is suggested that the private owners (additional local workshops) who had not joined in on the first round of EPC are again contacted and invited to participate in the second round, which would (again) be led by the same public consortium. Many private owners could appreciate all the benefits of EPC refurbishment and the improved quality of the microenvironment (at no cost), which are visible in their vicinity; and they may decide to join in on the second round of EPC (Step 12). It is also suggested that the same operation is repeated again after 3-4 years (Step 14). With this gradual non-mandatory EPC participation of different stakeholders in various stages, it is possible to achieve an almost complete green retrofit of an entire central district in a reasonable period of time.

Impact

The energy performance of historic buildings is a balancing act between heritage significance (preserving heritage values) and energy efficiency measures (achieving energy saving) [35]. This characteristic differentiates the green retrofitting of heritage neighbourhoods in comparison to the “regular” building stock [37]. In the last years, it was possible to experience a substantial development of new concepts focusing on rehabilitation of historic urban areas, which comprises a greater awareness of historic heritage, the role of public space, the intangible values of identity, social integration, etc. Heritage represents an essential resource in the cities where its rehabilitation should take into consideration the tangible and intangible features with special attention to the residents’ quality of life [41]. Moreover, the energy retrofit of protected buildings in historic districts can also help attain EU climate targets [6].

The innovative EPC^{HC} could open a new perspective on district green retrofitting and could facilitate the approach of large-scale EPC implementation in historical city centres. The innovative procedural model EPC^{HC} offers step-by-step guidelines with concrete suggestions to be followed in order to approach and involve all the different stakeholders - from the initial pre-planning to the complete renovation of the historic district with EPC. Through this model, it is possible to obtain a wider picture/overview of possible obstacles and solutions for such complex refurbishment. Cities around the globe will undergo a radical transformation toward sustainable urbanism in the next two decades. We will experience the construction of hundreds of sustainable neighbourhoods and eco-cities around the world, and the main question will be how to finance the implementation of comprehensive sustainable urban features. One of the main answers is the EPC funding model, which could also be re-interpreted and applied beyond the energy retrofit purpose (for real estate) to other areas of interest in cities such as transportation, recycling or natural resource preservation systems.

Conclusion

Kyrö et al. [11] identified the need for a suitable process tool - governance model to be provided for all the stakeholders involved, which could enable effective and profitable refurbishment projects. The article

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presents concrete recommendations on how to approach historic urban districts with EPC. There are three different common aspects in historical central districts that are taken into consideration in the EPC^{HC} matrix: district scale refurbishment, cultural heritage preservation and multi-stakeholder governance/assembly. The involvement of a large number of buildings represents an added value and could boost EPC implementation. The economy of scale diminishes EPC administrative costs, and at the same time diminishes the investment risks. Apart from the funding issue, one of the main challenges for refurbishing historic buildings is finding an adequate balance between respecting cultural heritage and applying energy efficiency measures. Evidently, EPC in historical city centres is less profitable in comparison to urban areas without buildings of cultural significance. However, because historical city centres have symbolic and touristic relevance, the extra investment in cultural heritage preservation is undoubtedly worth the expense.

The other defining characteristic of city centres is that they encompass several very different building owners/stakeholders (commercial, residential, and public - municipal, regional, government). One of the main challenges for the EPC^{HC} model is, first, the achievement of the “collective commitment” of all the stakeholders involved. The limitation of the proposed model is that it necessitates a positive outlook on the part of multiple owners (from the public and private spheres, including regular citizens, companies and institutions) to join in on the project. A considerable proportion of state-owned buildings is an important advantage for EPC. Naturally, it is important to point out that public stakeholders should work together, even if there are different political interests between regional, state or municipal authorities. The public consortium should be the most cohesive and active stakeholder in the project, which could represent a challenge if particular ministries do not collaborate or if local public institutions do not cooperate with national institutions. It was identified that the public consortium which encompasses all the municipal, governmental and state-owned buildings, should be the initiator, facilitator and administrator of the entire EPC process in city centres.
The public consortium, led by the city authority (UFMU), might also be responsible for EPC related procedural steps, and (in collaboration with a selected ESCO) for the coordination of special tailor-made interventions related to the cultural heritage specifics of the buildings (cultural heritage pre-intervention analysis, energy efficiency solutions, etc.). In addition, one of the most important activities of the public consortium is to adequately promote all the benefits and to attract private commercial entities and residential individuals to participate. Another challenge represents the establishment of special “urban facility management unit” (UFMU). In their study, Polzin et al.[42] have identified that in general, municipalities do not possess enough internal human resources with the specific managerial capacities to deal with the complex energy refurbishment systems, and they would likely need to hire new employees. Although opting for EPC might reduce the need for in-house expertise to retrofit districts, trained and experienced employees are still needed to manage the whole contract process with the ESCOs. Inadequately trained personnel for the management of EPC represents one of the most important barriers for municipalities [42]. The question that could arise is where to find the additional budget for the new UFMU employees. The role of government and transnational bodies within the EPC^{HC} are expressed in two ways. Firstly, to finance the activator/facilitator, who organises the entire EPC process, supports, and connects different stakeholders. Secondly, through government and transnational funds/subsidies which directly target the refurbishment of historic urban areas and cover the extra refurbishment costs for the preservation of cultural heritage.

Conflict of interest
There are no conflicts to declare.

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DO THE INNOVATION AND DIGITAL TRANSFORMATION STRATEGIES INDUCE SME PERFORMANCES IN NEW NORMAL ERA? STRUCTRUAL & CONFIRMATORY ANALYSIS MODELS

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Highlight
Exploratory and confirmatory factor analysis EFA, CFA, and SEM models, using SPSS.26.Smart PLS-SEM about the reasons of digitization process difficulties and recommendations for healthcare sector in Germany.

Abstract
One of major challenge in a sustainable growth, which organizations face is a slow adoption of the digital transformation. This research work presents the reasons that lead to the slow digitization process in medical device SMEs in southern Germany. In addition, by developing the conceptual model, this work highlights the effect of these improper implementations on SME's business performances and financial situation. The researchers applied correlational research design methodology, with simple random sampling techniques along with empirical and statistical study with primary data collection. The main study variables are SME's financial situation, SMEs organizational performance, and medical digitization rules. The study demonstrated the negative impact of delayed digital mechanisms in terms of businesses and financial performances.The extra transparency restrictions that add burdens for SMEs, and the lack of training for the employees, which in overall add more difficulties for adopting innovation and digital transformation are other factors negatively affecting the studied process.

Keywords
digitization; innovation theories; inferential statistics; confirmatory factor analysis; structural equational modelling.

Introduction
The Healthcare sector in general and medical device industry in specific are considered to be of paramount importance/need for most people, and it has faced significant challenges in recent times due to the outbreak of the COVID-19 pandemic. Hence, it is important for the SME to effectively implement changes and sustain competitive advantages. As the results of rapid globalization, the global market for medical devices is growing to sustain a delivery of appropriate healthcare services and find new distribution channels for their items. According to Wilson [1], the organization's senior management tried to find new strategies and take the necessary steps to capitalize on new markets or approach new market trends on a global level. Based on a study

of Padro & Green [2], the economic conditions have changed drastically in recent years, thus medical device companies should adapt to these changes as well. More innovation-based initiatives are therefore required to find solutions that reduce healthcare expenditures while enhancing the quality of healthcare services. The leadership position is seen as the most vital in this regard, with internal and external drivers that applied to medical SMEs do not provide the best offer according to the individuals' interest.

Modern technology introduces numerous opportunities for businesses concerning innovation protocols [3, 4]. Some of these technologies are ready to implement, low-price, flexible, highly customizable, and provide extra-quality for user interaction [5]. In addition, some studies have shown that the diversity of physical and digital technology significantly contributes to the development of innovation strategies and has a high potential to influence entrepreneurship outcomes in SME services and operations [5–7]. As for the digitization of products and performances, it implies a great degree of resilience through a supply that continues to evolve, even after entering the global market. Due to this type of technology, entrepreneurs can constantly reassess their market value and easily submit proposals according to the redefining potential business proposal [5]. As a result, entrepreneurs are moving towards finding more dynamic innovation and entrepreneurial pathways, as they cannot facilitate their implementation by use of innovative technologies [5]. Using innovative strategies enable entrepreneurial processes, and facilitates innovative business models, as well as maximum business scalability [8]. At the same time, it drives the capital ability to improve capabilities and performance easily and at a less cost. Furthermore, an organization's strategic and competitive goals can be achieved by adopting innovative technology to accelerate the process of transformation and digitization used by the organization to approach the strategic vision of the respective firms.

The Medical Device Industry is the one with increasing quality standards and rigorous compliance restrictions due to globalization and transparency issues. Hertling et al. [9] defined the process of digitization as an umbrella term used for referring to a society's digital transformation. They describe it as a transition from analogue technologies to digital ones, as well as to and digital innovation in general. This has an impact on all aspects of life, including healthcare industry. The purpose of this study is to explore to what extent adopting innovations and digital transformation processes can affect SMEs' performance in medical device sectors in the context of the new era after the outbreak of the COVID-19 pandemic. The scope of research focused on companies located in the Bavaria, the southern region of Germany, particularly on the SMEs that adopted the digital transformation process because of the pandemic. The research objective is to investigate how the leaders in the medical device industry are facing the current challenges and the process of transformation. Moreover, the research spotted factors that delayed the digitization protocols in SMEs [10], in addition this work aims to draft recommendations for senior management and management information system specialists on how to utilize the data and research aiming at overseeing the current situation in medical device industries. Medium and small companies need to identify and explore the opportunities introduced by innovative digital technologies, particularly in new start-ups [11]. SMEs are especially susceptible to crises [12]. Their strategic options for managing the COVID-19 situation have been limited by a lack of resources and poor readiness for a new situation. Therefore, innovation strategies are an important business channel for SMEs, large-sized companies, and start-ups in different fields [13].

The delay and slow digital transformation have raised concerns about the insufficient efforts and implementation terms for transformation mechanisms, as well as worries the commercial benefits for SMEs [14]. This might have negative consequences on society and patient risk [15]. Medical devices are considered to be the key factor in medical and healthcare technology to enhance processes for millions of patients [16]. According to de Mol et al. [17], the firms' rules can promote creativity and innovation since they allow the replacement of outdated technology with more advanced, efficient and secure options [18]. Yet, the transformation rate is not enough to improve the company's performance. One of the most well-known theories of innovation is Rogers, which focuses on any innovative measures an entrepreneur takes to lower overall production costs or boost demand for his/her products [19]. Rogers et al. [19] stated that anybody desiring profits must innovate. After reviewing the literature in this regard, the scarcity of studies that focused on the point of digital transformation implications on healthcare SMEs in Germany, particularly in the southern region has been identified. Additional ambitions to conduct this research include the case studies techniques, which are relied on empirical evidence based to the research topic [19–21]. The previous studies spotted the phenomenon of the delayed digital transformation process in Germany [22]; however, the factors influencing the relations statistically the most followed by the recommendations are spotted in this work. Hence, the presented research opens the gate for more study, especially for Management Information Systems (MIS) specialists to develop more protocols in digital transformation. This work demonstrates the empirical research study about the implications of adopting rapid digital transformation techniques on medical device companies. In addition, SME's innovation strategies and performances in the southern German region of Bavaria, two years after the outbreak of COVID-19. This work presents the primary data collection and robust empirical statistical validation tests to define the relationship between studied variables and illustrate the conclusions and recommendations accordingly.

Medical Device Industry in Europe.

Europe has faced a substantial growth in recent years in the field of patient care and medical devices sector. The medical devices industry is becoming crucial in clinical practices since it is improving the quality of life and health of its patients. The industry is appealing to, producers, developers, and investors due to the consistently high demand of patients and healthcare providers, as well as being a high profit margin business area [23,24]. On a global level, there are many SMEs operating in this field. The large number of businesses in the European market also supports this reality. Revolutionary medical devices are frequently created by small, medium-sized creative companies, and by small businesses in the field of medical devices. Smaller businesses expand more rapidly, as they are easier to manage in comparison to large businesses, since the inventor are often the owner, leader, and a decision-maker. Therefore, making decisions and calculating risks is straightforward. However, in larger businesses management, leadership and research are divided among diverse levels and do not a sole leader or decision maker. SMEs consist of 95% of medical device developers in Europe. Those small to medium-size businesses usually experience large administrative costs, which makes them vulnerable to failure. In order to succeed and bring up the SMEs' ideas to the market, they must engage with the medical device regulations [25]. As the industry has adapted to unavoidable change because of COVID-19, the adaptations and innovations adopted will result in permanent metamorphosis. With the acquisition of new digital and virtual skill sets, digital transformations within the industry that may have previously suffered from inertia have accelerated quickly. Companies have evolved to deliver better, more efficient ways of treating patients, providing services to healthcare professionals, and managing clinical studies [26].

Innovation and the New transformation in Medical Device Sector.

Medical Technologies equipment is changing rapidly and is facing pressure from all directions. Their widespread publicity is due to patients placing more demands on the newest discoveries. The Medical Device SME sought to change the inherent flaws as well as to catch up with the quick advancement of science and technology in the medical device industry by carrying out the digitization process, especially after the outbreak of pandemic [27]. Manufacturers and designers can use those technologies to their benefit and innovate, as they can follow clearer guidelines. The success of medical device development is based on a variety of factors, including financial analysis, planning, creativity, and customer feedback at the time of the development process, as well as business employee involvement in the development of new products [28]. In Rogers's words, innovation is a "procedure of many industrial practices that reshapes the economic structure from inside, erasing the old version and constantly building a new model" [19]. According to Roger the four aspects of innovation are invention dissemination, and imitation [19].Therefore, the importance of innovation in the field of medical services and its impact on the economy is usually related to the establishment of regulations on a national and international level [29]. The vast bulk of studies, which applied Rogers' Diffusion of Innovation Theory is related specifically to technological and scientific innovations, adoption, uses, and practices [30–32]. The Theory of Economic Development and the following writings classified the historical process of structural changes that characterizes development into five categories starting with the introduction of a new product alternative for the current product, then utilizing innovative manufacturing or marketing methods, in addition to penetrating and presenting the company portfolio in new markets" [33]. In addition, securing new sources of raw materials or industry inputs will lead to a different utilization of the available resources for productive methods in the economy [34].

According to Raynard [35], innovation is essential for competitiveness and economic development. In addition, the shared Rogers's viewpoint that innovation, is the driving force behind economic transformation and creative construction [19]. Back to Rogers's view [19], the actions of the entrepreneurs to innovate, using scientific and technological invasions open up new doors for employment, investments, and expansions. Additionally, small, and medium-sized businesses have access to a wide range of opportunities due to digital transformations and innovative technologies. These technologies can be utilized to create entirely new business models, acquire more business opportunities, and develop consumer loyalty [36]. Giebe, stated that German businesses are not in a bad situation in regard to digitization [21]. Germany is a leader in innovation, particularly in Europe, and it

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excels in several key technologies that are crucial for the digitization of society. However, it seems that other nations, particularly the USA and China are frequently better at turning innovative ideas into profitable businesses. Meanwhile, Germany still not yet utilized the main benefits that small firms use from applying innovation, and productivity techniques. Since the start-up growth percentage in Germany is rather small and its reduced in the last few years [37]. One of reasons behind this is a need of the digital transformation and digital innovation [38], which in turn have a negative impact on a digital technology implementation [20]. Hence, it is important to encourage investment in Germany and, more importantly, to remove barriers, so that a transformation takes place and increases the companies' incomes [22].

Methods

Research Objectives.

The main objective of the research is to indicate the reasons behind the delayed stage of digital transformation and innovations process for SMEs in the medical sector and to define the implications of adopting modern technology in it, such as total transfer from paper and documentation work to the digitization and online communications system, as the total quality and management systems. Hence, the research objectives can be illustrated, as follow:

- to investigate the effect of implementing innovations & technologies on SMEs' financial situation.
- to highlight to what extent the new digitization processes induced the business performance in the medical devices field in Germany.
- to craft recommendations for better practices in the medical devices sector in terms of accelerating the transformation stages. This in turn translates into the following research questions:
    a. What is the impact of applying the innovation process on an SME's financial situation?
    b. To what extent are the SME's business performances affected by the implementation of medical digitization regulation MEDR?

Conceptual Framework

The conceptual framework shown in Figure 1 is based on the input-output process model. The input process consists of the following:

Dependent variables:

- The SME's financial situation (SMEF) includes two factors: Financial burdens and Commercial Performance;
- The SMEs organizational performance (SMP) with two factors, namely SMEs digitization Strategy and a Business Growth.

Independent Variable is Implementations of Medical digitization regulation (MEDR), which include two factors: Slow Innovation process and Transparency restrictions.

Process methods

The implementation of the conceptual framework has been carried by the processing of the collected data using inferential statistics techniques, Exploratory Factor Analysis (EFA) for validating and Confirmatory Factor Analysis (CFA) and Structural Equation Model (SEM).

Output Method

Discover the impact of applying digital transformation on SME performances, detecting the reasons for delaying a complete digital transformation.

Hypotheses development

Currently, there are different studies investigating the performances of multinational companies [39]. Nevertheless, the SME's performance after the outbreak of COVID-19 in the medical devices sector and the impact of innovation and digitization on business and financial performances still needs lighter to be shed on this sector. Therefore, the hypothesize of this study is as follows:

SME financial performances (SMEF)

The financial performances of SMEs are regarded as the main indicator of an organization's growth [40] hence, this the first hypothesis of this work is to investigate the relationship between an organization's financial performance (SMF) and its implementation of medical digitization technology and regulations (MEDR). This variable consists of two factors: firstly, the financial burdens; secondly, the commercial performance. H1:

Investigate the Relationship between SMEs' Financial Performances (SMEF) and Regulation Implementations (MEDR).

Since the financial situation reflects the rate of achievement of the organization [23], this work demonstrates the hypotheses H1.1 & H1.2 to highlight the relationship between delays in the digital transformation process and the SME financial burden. In addition, the transparency process, to reveal most of the essential data in the digitization process added more burdens to the transformation process [20]. Therefore, hypotheses H1.3 & H1.4 were proposed and are focused on the relation between transparency enhancement and restrictions in the digitization process and financial performances.

H1.1: The slow digital transformation process does not affect SME financial burdens.
H1.2: The slow digital transformation process does not affect SME commercial performances.
H1.3: The transparency restrictions in SMEs do not affect financial burdens.
H1.4: The transparency restrictions in SMEs do not affect commercial performances.

SME organisational performances (SMP).
H2: Investigate the relationship between SMEs' organizational Performances (SMP) and Regulation Implementations (MEDR). Digital transformation and innovation models have put an extra load on traditional companies [41]. By reviewing the extant literature, the acceleration rhythm and strategies for the digitization process in multinational companies [42] have been identified, however the point of SME is still voided. For that purpose, we developed hypotheses 2.1 & 2.2 to detect the relationship between the delayed digital transformation process and SME performances as implementation strategies for the complete digitization process. In meantime the hypotheses 2.3 &2.4 will define the impact of transparency restrictions on digital transformation and business growth.

H2.1: The slow digital transformation process has a negative impact on SME digitization strategies.
H2.2: The slow digital transformation process affected SME business growth negatively.
H2.3: The transparency restrictions in SMEs do not affect digitization strategies implementation.
H2.4: The transparency restrictions in SMEs do not affect business growth.

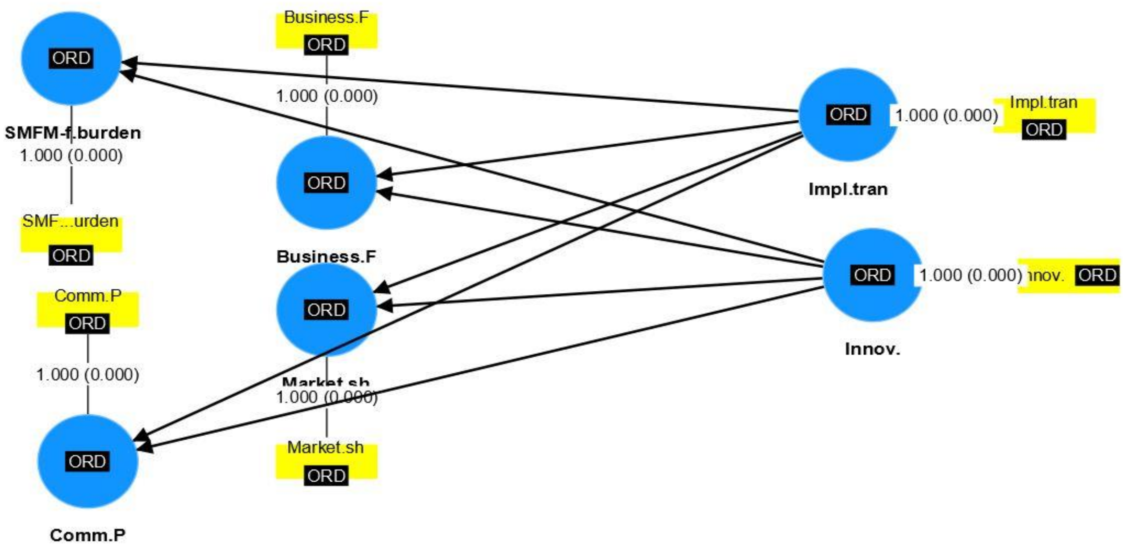

Figure 1. Conceptual framework, relations between study variables SME's financial situation (SMEF), SMEs organizational performance (SMEP) and Medical Digitization Regulations (MDR) by using PLS-SEM 4. *Source: [31].*

<u>Research Design</u>
The research design is based on correlational design. The data were collected from the selected samples of his population to investigate the outputs of correlational research, and then to examine the relationship between study-dependent SME's financial situation (SMEF), organisational performance (SMP) and independent variables of medical digitization regulations (MEDR). Usually, the correlational design determines the relation between studied variables in both directions, either positive, negative, or zero relations, and explores

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the frequent or infrequent relation among variables [43]. The data were gathered and administered by a survey of 105 respondents from medical device companies in the southern of Germany. The reason behind implementing this research design was to gather socio-economic data to explain the effect of applying (MEDR) on the SME's organisational and financial performance in medical field companies, the respondent's profiles and their feedback on the MEDR process and the extent and consequences of applying this technology in different companies. The data finding is calculated by inferential statistics for investigation of the correlational research design approach**.**

Research Population

The study geographically focused on the major SMEs in the Bavarian region represented by in Munich and Baden-Württemberg Region especially in Stuttgart, Nürnberg, and Frankfurt. The German Federal Statistics Office and Medtech Europe facts and figures from 2021 defined the number of medical device companies in Bavarian and Baden-Württemberg territories at 193, and 274, respectively. Therefore, the total medical device companies' population is 467. These two regions were chosen to conduct the study since the majority of healthcare SMEs and medical devices are localized in these areas. Top of that, they are easily accessible, well-staffed, and organized companies. The other business in other provinces have very few individuals to be represented in this research.

Research Sampling

The probability sampling concept by conducting a simple random technique was used in this work. In a simple random sampling method, every company of the population has an even chance to be involved in the sampling process. The sample size is formulated by a formula, which calculated the sampling size using the probability factor for population (P) formula, as follows: $P = 1 - (1 - (1/N))n$. where N represents the main population, and n represents the sampling size, considering P of 0.10, and N of 467, the obtained value of n is 47. By such means 47 companies were randomly selected from the population of 467 SMEs. The purpose of selecting this method is because it is the most reliable technique among probability approaches, as it performs a single random selection step, and it considers the awareness about the general population. Moreover, the randomization in the sampling technique requires a high value of validation process for the collected data [44].

Research Respondents

The questionnaire was circulated to the randomly selected SMEs and was available at the time of data collection to function as research respondents. The researchers received 105 complete responses from 27 companies of the considered population.

Instrumentation

The research instrument consisted of three variables, with a total of 36 factors. The first section considered the medical digitization regulation variables parts including innovation, transparency, and implementation. The second part of the questionnaire was designed for the SMP organizational performance, the context of corporate development and existing challenges. Equally important regarding the SME's overall output were the consequences of applying the contemporary restrictions to emphasize the beginning of the proper corporate supervision in order to develop the staff and fulfil the scientific inquires. The survey's third section was related to the financial and marketing burdens for SMEF. Each broad category, into which the questionnaire was organized, was composed of several relevant questions. The specific questions highlighted the possibilities of the chosen indicators that were approved in the activities with responses [45]. The survey adopted a Likert pattern of five points rating scale starting from "completely agree" to "completely disagree". The numerical system for responses facilitates the interpretation of the collected data.

Survey Construct Validation

To validate the collected data, the composite reliability approach was applied to assess the internal consistency after conducting factor loading analysis. The non-observable variable that affects more than one known indicator and explains the relations between these observed variables was called a factor. A relatively small number of variables used to indicate relationships between a group of items on a measure or a set of data can be found using statistical approach as shown elsewhere [46].

Composite reliability

Cronbach's Alpha composite reliability measures the internal consistency of scale items [47]. According

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to Brunner and Süß [48], it is equal to the entire amount of actual score variance and the total scale score variance. The obtained results are shown in Table 1.

KMO & Bartlett's Test of Sphericity

In the second step of the validation process, the Bartlett test and Kaiser Measure of Overall (KMO) were calculated to validate sampling adequacy, since the larger data size makes it overly sensitive to even minor deviations in the adequacy of KMO-test samples concerning the appropriateness of the data for factor analysis [49].

The result of the KMO test was 0.883, i.e., more than 0.80, which means that it is statistically significant [50]. As such, in regard to Bartlett's test, p = 0.000, which means that it is statistically significant, and the values refer to the adequacy of the sample for both the KMO and the Bartlett's tests.

Table 1. Composite reliability results computed using Excel & SPSS 26. *Source: Authors.*

No	**Variables**	**Composite Reliability coefficient**
1	SMP	0.82
2	SMEF	0.77
3	MEDR	0.83

Factor Analysis

The exploratory factor analysis (EFA) was applied to highlight the presence of latent variables in the collected data [51]. The EFA factor structure allows resulting in each variable representing a different construct [52]. The factor analysis for the study variables produced six factors distributed in two for each variable as shown in Tables 2-4.

Table 2. Factor lading for SMEs Financial situation results. *Source: Authors.*

Factors	**Components**	
	Financial Burdens	Commercial Performance
SMEF4	0.890	−0.109
SMEF2	0.843	−0.169
SMEF1	0.619	
SMEF5	0.612	
SMEF3	0.417	
SMEF6	−0.112	0.993

Table 3. Factor lading for MEDR implementation results. *Source: Authors.*

Factors	**Components**	
	MEDR Implementation	Transparency
MEDR7	0.80	−0.371
MEDR1	−0.690	0.345
MEDR11	0.670	0.252
MEDR6	0.670	−0.262
MEDR4	0.650	−0.162
MEDR8	0.596	
MEDR2	0.520	−0.311
MEDR9		0.918
MEDR5		0.567
MEDR3	−0.208	0.384

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Table 4. Factor lading for SMEs performance SMP results. *Source: Authors.*

Factors	**Components**	
	Innova	Business Growth
SMP2	0.760	−0.124
SMP1	0.720	−0.264
SMP5	0.70	
SMP3	0.660	
SMP7	0.650	−0.226
SMP6	0.460	0.135

Results and discussion

The dataset was statistically computed by using (SPSS) Statistical Package for Social Science version 26 and Smart PLS-SEM 4. The studied design was assessed using inferential statistical methods. The inferential contains regression for the independent variable, correlation, and linear regression to investigate the relationship between research variables followed by the SEM path analysis model.

<u>Inferential Analysis Finding</u>

The inferential statistical method is a producer applying statistical tools to investigate the conclusion and properties of the main population by using a simple random sample to approve or reject the hypotheses [53]. The researchers computed the inferential statistics techniques to illustrate the final findings and results of this research by using multicollinearity regression, Pearson correlation, and multi-regression.

Table 5. Pearson correlation between variables. *Source: Authors.*

	Variables	**1**	**2**	**3**	**4**	**5**	**6**
1	MEDR. Implement	1					
2	Transparency	0.22	1				
3	Innovation	−0.41 **	−0.62**	1			
4	Buss. Growth	−0.63 **	−0.16	0.41 **	1		
5	Finance. Burdens	−0.55 **	−0.11	0.56 **	0.63 **	1	
6	Comm. Perform	−0.48 **	−0.26 **	0.43 **	0.52 **	0.70 **	1

N = 105. ** p < 0.01. level.

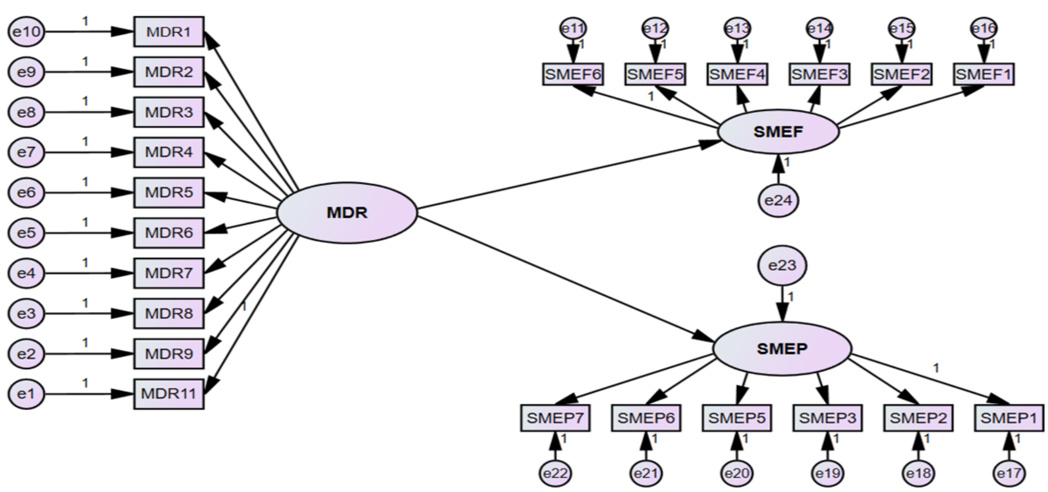

Figure 2. Structural Equation Model (SEM) for study variables using SPSS AMOs-26. *Source: Authors.*

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Table 6 Regression weights default SEM model by SPSS AMOs-26. *Source: Authors.*

			Estimate	**S.E.**	**C.R.**	**P**
SMEP	<---	MDR	-2.253	0.672	-3.354	***
SMEF	<---	MDR	-1.935	0.595	-3.251	0.001

Standard Error - S.E, Critical Ratios - C.R

The computed model was fit based on the model shown in Figure 2. The fit indexes of this CFA model (chi-square 300.605; degrees of freedom (df) 207; CMIN/df : 1.452, root mean square error of approximation (RMSEA): 0.066; comparative fit index (CFI) 0.929; standardized root means square residual (SRMR) 0.055 showed an acceptable fit with the data and met the conventional thresholds suggested by Hu et al. [54].
According to Table 6, the effect of MDR implementations on SME's business performance and the link between dependent (SMEP) SME's business performance and independent variables (MDR implementation) & (transparency protocols) is indicated by the estimated value. The value shown in Table 6 is -2.253, which is statistically significant (p-value for MDR is 0). Additionally, the p-value of SMEF is .001 also showed the significance of this regression model. Estimated values explain the degree of variations, which take place in dependent variables SMEP and SMEF, as the results of the independent variable (MDR). As shown in Table 8 for each 1% MDR implementation increase, the SMEP business growth will decrease by 2.253%. Likewise, for commercial performance, the results detected the relation with MDR as follows: for each 1% of MDR implementation increase the SMEP innovation strategies will decrease by 1.935%.

<u>Hypothesis testing</u>

- Hypothesis 1

As shown in Table 6, the results detected a significant negative relationship between MEDR slow implementation and financial burdens and commercial performance. The values of both variables at correlations are −0.55 ** and −0.48 **, respectively with p-value of 0.000, <0.01. This means that the H1.1 &H1.2 can be rejected, and the alternative hypothesis is valid. According to this finding, the impractical and slow implementation of digital transformation, MEDR adds an extra financial burden for SMEs in the medical devices industry in Germany. The current rhythm is not sufficient to apply the full MEDR effectively. In addition, insufficient training added extra limitations and barriers to apply the recent technology advances. Regarding hypothesis 1.3, the obtained value is 0.11 (Table 6), hence, there is no meaningful relationship between MEDR implementation and SMEF financial burdens. On the other hand, there is a committed relationship between MEDR transparency enhancement and SME's commercial performances (SMEF), for which the value is 0.26**, p-value = 0.000, <0.01. These results reject the null hypothesis 1.4 and approve the alternate one by detecting the meaningful relationship between two variables.

- Hypothesis 2

The correlation matrix results detected a significant negative relationship between MEDR implementation, SMP innovation digitization strategy, and business growth, as shown in Table 6. The values of both are −0.41 ** and −0.63 **, respectively, with p-value of 0.000, <0.01, which approved the hypotheses H2.1 and H2.2. According to a study finding, the slow implementation of MEDR inhibited the innovation strategies in SMEs. As a result, the extended time for applying the digital transformation from 13 to 18 months has a negative impact on business growth. In the same way, the correlation matrix results spotted strong negative relation between the MEDR transparency restrictions and improving the innovation strategies in SME with −0.62 ** and p-value = 0.000, <0.01, which rejects the null hypothesis H2.3 and approve the alternate hypothesis about the negative effect of transparency shortage and non-relevant data on the innovation strategies. On the contrary, the correlation test for the study variables could not detect any relation between the MEDR transparency restrictions and SME's business growth, which approved H2.4 null hypothesis.

<u>Regressions Values</u>

In this work, multi-regression analysis between study variables was conducted as the second step of inferential statistics after CFA and SEM and was used for interpretating and investigating the direct effect of independent variable MEDR on dependent SMEF & SMP variables to answer the research questions.

<u>Regression Values for Question Number 1</u>

The effect of implementing the MEDR on SMEF's financial situation. The link between the dependent(SMF) SME's

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financial performance and independent variables (MEDR implementation and transparency restrictions) is indicated by the R-value. Normally, the value should be more than 0.4 [55]. The value shown in Table 7 is 0.784, which is favourable for further examination. R^2 displays the overall variation of the dependent variable, which help the independent factors interpret in the regression models [56]. The obtained value is 0.614, i.e., higher than 0.5 and indicates that the model is applicable for identifying the relationship. The adjusted R-square demonstrates the generalization of the results or the variation of the sample results from the main population. It should have a slight difference between the R-square and Adjusted R-square of about ±10%, which is observed in this case too.

ANOVA significance value is calculated with a confidential interval CI rate of 95% and the significant value should be less than 0.05% [57]. The results in Table 7 are 0.000, which is an applicable percentage. Therefore, for F, the value refers to the emphasis of variables predictions, which fit in the regression model as the expected value should be above 1 [58], whereas the result is 22.690. The p-value shows the validity and significance of bothindependent variables, MEDR implementation and transparency restrictions to be stated in this regression model separately. The results for the MEDR variable are 0.000, which is statistically significant. Conversely, the p-values of transparency are 0.836, 0.063, which means that these variables are not relevant for these regression models. This in turn fits to the same findings as those from the correlation matrix, and the application of transparency protocols did not affect the financial performance of SMEF. Beta (B) values explain the degree of variation occurring in dependent variables (SMEF) as the result of an independent variable (MEDR) [59]. As shown in Table 8, for each 1% of MEDR slow implementation increase, the SME’s financial burdens will decrease by 0.486%. Likewise, for commercial performance, the results detected the relation with MEDR as below: for each 1% of MEDR implementation increase, the SME’s commercial performance will decrease by 0.445%.

Table 7. Question 1 R values and ANOVA values in the regression model using SPSS 26. *Source: Authors.*

Model Summary						
Model	R	R Square		Adjusted R Square		Std. Error of the Estimate
1	0.784	0.614		0.611		0.271
ANOVA						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	18.340	2	9.170	22.690	0.000 [b]
	Residual	41.222	102	0.404		
	Total	59.562	104			

[a] Dependent Variable: SMEF; [b] Predictors: (Constant), MEDR Transparency, MEDR. Implement.

Table 8. Question 1 Coefficient values a1 & a2 in the regression model. using SPSS 26. *Source: Authors.*

Model a1		**Unstandardized Coefficients**		**Standardized Coefficients**	**T**	**Sig.**
		B	Std. Error	Beta		
a1	(Constant)	3.788	0.319		11.869	0.000
	MEDR. Implement	−0.486	0.074	−0.559	−6.611	0.000
	Transparency	0.015	0.073	0.018	0.208	0.836
Model a2		**Unstandardized Coefficients**		**Standardized Coefficients**	**T**	**Sig.**
		B	Std. Error	Beta		
a2	(Constant)	4.322	0.380		11.368	0.000
	MEDR. Implement	−0.445	0.088	−0.445	−5.081	0.000
	Transparency	−0.160	0.087	−0.162	−1.847	0.068

a1. Dependent Variable: Finance. Perform; a2. Dependent Variable: Comm. Perform.

Regression Values for Question Number 2

The effect of MEDR implementations on SMEs’ business performance.

The link between the dependent (SMP) SME’s business performance and independent variables (MEDR

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implementation) and (transparency protocols) is indicated by the R-value. The value shown in Table 9 is 0.921, which is favourable for further examination. R-square is 0.849, which is also acceptable, since the adjusted R-square value is 0.847 which is favourable. According to the results in Table 9, the p value is 0.000%, which mean it is statistically significant. Meanwhile, the result for the F value is of 10.896, which is favourable.

The p-value for MEDR is 0.000 which is statistically significant. Conversely, the p-values of transparency are 0.806 and 0.334, which means that these variables are not relevant for these regression models. Beta (B) values explain the degree of variations that happens in dependent variables (SMP) as the result of the independent variable (MEDR). As shown in Table 10 for each 1% MEDR implementation increases the SMP business growth will decrease by 0.657%. Likewise, for commercial performance, the results detected the relation with MEDR as below: for each 1% of MEDR implementation increase, the SMP innovation strategies will decrease by 0.325%.

Table 9. Question 2, R and ANOVA values in regression model. *Source: Authors.*

Model Summary						
Model	R	R Square		Adjusted R Square	Std. error of the estimate	
1	0.921	0.849		0.847	0.154	
ANOVA						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.880	2	3.940	10.896	0.000 [b]
	Residual	36.882	102	0.362		
	Total	44.762	104			

[a] Dependent Variable: Innovation; [b] Predictors: (Constant), Transparency, MEDR. Implement.

Table 10. Question 2, Coefficients values a2.1 & a2.2 in regression model. *Source: Authors.*

Coefficients						
Model a2.1		**Unstandardized Coefficients**		**Standardized Coefficients**	**T**	**Sig.**
		B	Std. Error	Beta		
a2.1	(Constant)	4.426	0.364		12.175	0.000
	MEDR. Implement	−0.657	0.084	−0.621	−7.836	0.000
	Transparency	−0.020	0.083	−0.019	−0.246	0.806
Model a2.2		**Unstandardized Coefficients**		**Standardized Coefficients**	**T**	**Sig.**
		B	Std. Error	Beta		
a2.2	(Constant)	3.203	0.302		10.610	0.000
	MEDR. Implement	−0.325	0.070	−0.430	−4.668	0.000
	Transparency	0.067	0.069	0.089	0.970	0.334

a2.1 Dependent Variable: Business Growth; a2.2 Dependent Variable: Innovation

Impact

The results highlighted a negative relationship between the slow pace of the digitization implementation strategy and financial burdens. According to a study, the unpractical and slow implementation of digital transformation adds an extra financial burden for SMEs in the medical devices industry in Germany. The current rhythm is not sufficient to apply the full digital transformations effectively. In addition, the lack of training added extra limitations and barriers to applying modern technology solutions. Additionally, there is a negative impact between transparency enhancement and SME's commercial performances (SMEF), as the restriction in transparency and data revealing process creates more difficulties for SMEs to fulfil the digital transformation process requirements. Consequently, numerous SMEs could be withdrawn from the market because of delayed in the processes. The slow implementation of MEDR inhibited the innovation strategies in SMEs. The research finding and collected dataset would be applicable for decision support system specialists (DSS) to develop strategies and business plans for the digitization process in other sectors.

Conclusions

The research's main objective was to elucidate out the reasons that lead to the slow digitization process in medical device SMEs in southern Germany, as well as to highlight the effect of improper implementations on SME's business performances and financial situation. The results concluded that the main reason for the slow digital transformation process was the lack of training for the company's employees, in addition to the short-term transition period. Moreover, improper digital transformation can result in a negative impact on business performance. However, it is not only the transformation processes that can affect the business, but also the working environment and to what extent the staff is ready for this drastic development. In the light of this, businesses must consider both the technological and human sides of digitization. It would be wise for the firms to ensure that their employees have control over the change process and access to the specialized knowledgeand skills they need to fulfil their assigned responsibilities. Besides that, continuous training is also one of the key factors for any enterprise to be competitive in the current digital context [8]. Concluding the main advance in this area can be achieved by considering the training programmes and extended period for the digitization process to facilitate the mission of SMEs in the medical devices field as well as to consider implementation the classified policies and transparency restrictions for the data handling and revealing process. This in turn, would help to overtake the limitations and help to address the future research. The key aspect would be to conduct future research on the larger sample of companies in Germany and Europe.

Conflict of interest

There are no conflicts to declare.

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EFFECTS OF FRUIT MATURITIES, COATINGS, AND STORAGE TEMPERATURES ON THE QUALITIES AND GREEN-LIFE OF CAVENDISH BANANA

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Highlight
fruit maturities; coatings and storage temperatures on Cavendish Banana.

Abstract
Cavendish banana is a climacteric fruit with a fast response to ethylene and a very high respiration rate during storage. Previous studies revealed that these characteristics shortened the green-life and fastened fruit damage, affecting the economic value. Therefore, this study aims to examine the effects of fruit maturity levels, coatings, and storage temperatures on the qualities and green-life of Cavendish banana. The result showed that the level of fruit maturity significantly increased the green-life duration, as well as maintained firmness, diameter loss, acidity, and starch content, but it had no effect on weight loss, °Brix, and glucose. Meanwhile, low temperature was able to delay senescence, promote starch degradation, as well as detain firmness and diameter loss. The results also showed that the combined application of maturity levels + temperatures affected all parameters, while maturities + coatings as well as coatings + storage had effects on firmness, acidity, and starch content. The 1% chitosan coating coverage was analyzed with a Scanning Electron Microscope (SEM), which showed fully covered surface of M1 finger rind tip and some crack points on finger rind base. Furthermore, there was full coverage on M2, and some crack points on M3.

Keywords
Cavendish banana; maturity; coating; storage; temperature.

Introduction
Cavendish banana is a fruit with high economic value and high nutritional contents, such as carbohydrates, minerals, as well as vitamins B6 and C. It is also a leading export commodity; hence, its production promotes international cooperation. Furthermore, the Indonesian government (2021) stated that in May 2021, Cavendish banana exports reached 5,500 tons [1]. It was exported globally in its green-life stage and received ethylene gassing to promote ripening with temperature treatment of 16°C in the market destination. Gonge (2013)

reported that the storage of fruits at 16ºC significantly affected the texture, flavor, color, and taste [2]. As a climacteric fruit, Cavendish banana has high respiration and ethylene production rates, which causes fast degradation of its qualities. Several studies reported the role of ethylene in the ripening process [3]. The high respiration and hormone production rates are believed to be the cause of the short shelf-life. Fruit coating is a post-harvest treatment, which can decrease the rate of respiration as well as lengthen the fruit shelf life [4]. Furthermore, chitosan is an edible coating, and it chemically plays a role in inhibiting the movement of O_2 and CO_2. The presence of materials, such as coating around fruits with low O_2 and high CO_2 is expected to reduce the respiration rate during storage [5] The application of chitosan causes the flesh of the fruit to be soft, but the skin remains green. This indicates that there is a need to add an anti-ethylene agent along with the treatment. The addition of other ingredients that can inhibit ethylene production is an effective way of controlling ripening in the fruit.

Gibberellic Acid (GA_3) is a growth regulator that can cause greening in citrus as well as delay the appearance of red color in tomatoes [6] It can also delay the ripening of bananas by counteracting ethylene and retaining chlorophyll, thereby maintaining the green color, minimum weight loss, percentage of moisture content, and low dry weight [7] The concentration of GA_3 greatly affects the success of its application. GA_3 can delay the ripening of Cavendish banana for 3-4 days at a concentration of 50-250 mg/L [8]. Several studies revealed that storage temperature also greatly affects the shelf life of fruit. Temperature has a direct effect on the rate of respiration, and at low levels, the rate is reduced. This is also supported by the delivery process of Cavendish banana, which are often given a low-temperature treatment ranging from 13-14ºC [9]. The combinations of fruit maturities, coatings, and storage temperatures can extend the shelf life of Cavendish banana. These treatments can reduce economic loss caused by missed green-life period during exportation as well as increase farmers' income. The materials needed for the treatment are easy to obtain and apply, as well as environmentally friendly [10]. Therefore, this study aims to examine the effects of fruit maturities, coatings, and storage temperatures on the qualities and green shelf-life of Cavendish banana.

Methods

This study was carried out in the Laboratory Horticulture and Postharvest, Department of Agronomy and Horticulture, Faculty of Agriculture, University of Lampung, Bandar Lampung, Lampung, Indonesia, from July to September 2022. The samples used consisted of fruit clusters from Cavendish banana fruit bunches with 3 levels of maturity, namely immature, full mature, and over mature.[11] The banana sample was received from Great Giant Foods Co. Ltd., Plantation Group 4, which is previously known as Nusantara Tropical Fruits Co. Ltd., Labuhan Ratu, East Lampung in stage I (green phase). The fruit was relatively uniform in terms of harvest age and physical appearance. Furthermore, this study used a Completely Randomized Design with a factorial 3 x 4 x 2 with 3 replications. The first factor was the banana fruit at 3 levels of maturities, namely physiologically immature M1 (5^{th} cluster), full mature M2 (3^{rd} cluster), and over mature M3 (1^{st} cluster) [11]. The second factor was the fruit coating, namely non-coating or control (C1), 1% chitosan (C2), 150 ppm GA_3 (C3), and 1% chitosan + 150 ppm GA_3 (C4), which were applied on the rind tip and base. The third factor was the storage temperature, including room S1 (27 ± 1ºC) and cold S2 (16 ± 1ºC) temperatures. The observation was discontinued in this study either when the fruit rind changed to stage III (greenish yellow) at the end of the green shelf-life, or flesh was softened or past 35 days in the postharvest handling.The variables examined include days of storage (green shelf-life), fruit firmness, weight loss, diameter loss, ºBrix, free acidity, glucose, starch, and SEM. The storage was measured by counting the days from the beginning to the end of observation. Furthermore, fruit firmness was analyzed with a penetrometer type FHM-5 Takemura Electric Work Ltd Japan, by peeling the skin of the sample. The process was carried out at three randomly selected locations around the middle or widest side of the Cavendish banana finger. Weight and diameter loss were analyzed using digital scales and vernier calipers. ºBrix was assessed with a digital refractometer by grinding the flesh of bananas with mortar and pestle, followed by filtration using filter paper to collect and drip liquid on the refractometer lens. Free acidity was analyzed using titration with 0.1 N NaOH and phenolphthalein as an indicator. The glucose and starch contents were assessed by adding saturated Pb-acetate, Na-oxalate, and aquades during sample extraction, followed by heating at 90ºC for 30 minutes. Furthermore, the rind surface pores were observed with Scanning Electron Microscope (SEM) by cutting the sample to the desired orientation, followed by fixation, dehydration, drying, and coating with a conductive layer. All data were analyzed with ANOVA, and further tested using Tukey's honestly significance difference (HSD) at 5% with the Minitab 19 version.

Results and Discussion

The observation of this study was terminated when the green-life of the banana ended with fruit flesh softening or 35 days of its shelf life. The green-life determines its shelf life and export quality, where the longer it is, the lower the risk of material loss during shipping time. This was because importers expect banana to arrive in their fresh green state before receiving ethylene gassing at the destination. Based on Table 1, the shelf life of Cavendish banana increased with the application of maturities, storage, maturities + storage, and coating + storage, but the use of only coatings had no effect. The best result was obtained from treatment M2S2, namely full maturity in cold storage with a shelf life of 34.75 days. This finding is consistent with Williams et. al. which reported similar results with the use of the treatment [12]. Meanwhile, fruit harvested at 75% maturity level and stored in a cold temperature of 12°C had a green-life period of 35 days [2].

Full physiological maturity refers to the maximum growth and maturation, and it marks the start of normal ripening. Fruit at this stage was able to reach the optimum performance when combined with cold storage. Furthermore, storage at low temperatures is one of the manipulation of environmental conditions, which can decrease metabolic activity rate substantially, and this prevents senescence and quality degradation [13]. Maturities significantly affected the firmness and diameter loss. Treatment M1 showed higher firmness and diameter loss, followed by M2 and M3. This was closely related to the determination of the maturity levels of the banana cluster that were taken as samples in this study, where M1 was immature with harder firmness than M2 and M3. This finding is consistent with Widodo et al. (2021), where the younger cluster, which is farther away from the stem showed a higher value of firmness [11]. The 1% chitosan coating on C2 and C4 was only applied on the fruit rind tip and base, and there was still uncover in some areas. Consequently, the use of this coating treatment had no significant effect on all parameters of observation. The application of control (C1) and GA_3 150 ppm on C3 and C4 showed no significant difference. Cold storage temperature lengthened the shelf life and maintained firmness but did not detain weight and diameter loss. This finding is in line with Ahmed et al. (2001) that storage temperature had no significant effect on banana weight loss [14]. Based on Table 2, maturities significantly affected acidity and decreased starch content, but did not affect other chemical qualities, such as °Brix and glucose. The observation of parameters was carried out with the same criteria for each sample in the same stage to ensure the °Brix is not affected. Glucose is a simple sugar or monosaccharide, and other forms of sugar were not observed in this study. This was suggested to be the cause of the lack of effect on the glucose content. °Brix, acidity, glucose, and starch were not significantly affected by the control treatment due to coatings and storage, except for the effect of storage treatment on starch content. Low storage temperature affected lowered the starch content due to accelerated degradation. Based on enzyme activities, this treatment facilitated starch degradation through the pathway of alpha-amylase over that of beta-amylase and showed different granule structures [15]. The combined application of maturities and coatings as well as coatings and storage temperatures affected the acidity and starch content. Meanwhile, maturities + storage temperatures had an effect on all observed chemical qualities, such as °Brix, acidity, glucose, and starch content compared to the control. The use of coatings mostly did not affect the parameters of observation because the application of 1% chitosan was carried out on the tip and base of the rind only. This indicates that the treatment cannot inhibit the movement of O_2 and CO_2 of the fruit and reduce the respiration rate due to the uncoated stomata areas. The results showed that the application of chitosan coating fully on the surface of rind fruit reduced weight loss and chemical quality, and increasing the concentration gave better results [16]. A previous study revealed that the use of full coating caused the fruit flesh to become soft [14]. This indicates that the application of chitosan on Cavendish banana must be carried out in full on the fruit rind in combination with anti-ethylene to produce a longer shelf life with good physical quality. Slower rates of weight loss in coated fruits can be attributed to the barrier properties for gas diffusion of stomata, the organelles that regulate the transpiration process, and gas exchange between the fruit and the environment [16]. Coating showed better results when combined with cold storage temperature, but longer shelf life was still shown by the control treatment at low temperatures.

Based on figure 1, The SEM analysis of the 1% chitosan coating showed that it fully covered the tip finger rind, but there are some crack points on the base on M1. It also revealed full cover on M2, and some crack points on M3. The same concentration of 1% chitosan coating on the surface of banana rinds at different maturity levels showed different results. Coating on fruit rind at full physiological maturity level (M2) showed better results than at other maturity levels. This might be influenced by different skin textures at each maturity level, fruit respiration rate and stomata conductance during application. However, similarities in the appearance of layers on different coating materials can occur because in the coated condition, the stomata on the fruit surface are covered by the coating materials have been previously reported [17] Fruit coating with commercial wax and Shellac coating on the surface of strawberry fruit showed homogenous and uniform layer [18].

Table 1. The Effect of Maturities, Coatings, and Storage on the Fruit Shelf Life, Firmness and Diameter Loss[1.] *Source: Author.*

Treatments[2]	**Shelf-life (days)**	**Firmness (kg/m²)**	**Weight Loss (%)**	**Diameter Loss (%)**
Maturities				
M1	28.31a	2.73a	0.21a	0.15a
M2	28.31a	1.66b	0.20a	0.12ab
M3	25.87b	1.47b	0.18a	0.10b
Coatings				
C1	28.00a	2.05a	0.20a	0.14a
C2	27.92a	2.03a	0.20a	0.13a
C3	27.25a	1.88a	0.20a	0.12a
C4	26.83a	1.86a	0.19a	0.12a
Storage				
S1	33.92a	2.39a	0.21a	0.13a
S2	21.08b	1.51b	0.18a	0.12a
Maturities* Coatings				
M2 C2	29.25a	1.63ab	0.19a	0.13a
M1 C1	29.00a	3.23a	0.20a	0.15a
M1 C2	28.75a	2.71ab	0.21a	0.13a
M2 C1	28.25a	1.05b	0.18a	0.11a
M2 C3	28.00a	1.26ab	0.20a	0.11a
M1 C3	27.75a	2.80ab	0.20a	0.18a
M1 C4	27.75a	2.19ab	0.22a	0.16a
M2 C4	27.75a	1.92ab	0.22a	0.15a
M3 C1	26.50a	1.36ab	0.19a	0.09a
M3 C4	26.25a	1.96ab	0.16a	0.10a
M3 C2	26.00a	1.81ab	0.20a	0.10a
M3 C3	24.75a	1.52ab	0.18a	0.10a
Maturities* Storage				
M2 S2	34.75a	0.75c	0.21ab	0.12ab
M1 S2	33.62a	2.24ab	0.22a	0.14ab
M3 S2	33.37a	1.55bc	0.20ab	0.12ab
M1 S1	23.00b	3.22a	0.20ab	0.16a
M2 S1	21.87b	2.19ab	0.19ab	0.13ab
M3 S1	18.37c	1.77bc	0.16b	0.078b
Coatings* Storage				
C1 S2	34.67a	1.34a	0.20a	0.11a
C2 S2	34.17a	1.64a	0.21a	0.11a
C4 S2	34.17a	1.73a	0.22a	0.15a
C3 S2	32.67a	1.35a	0.21a	0.14a
C2 S1	21.83b	2.46a	0.20a	0.13a
C1 S1	21.17b	2.42a	0.18a	0.12a
C3 S1	21.00b	2.37a	0.18a	0.12a
C4 S1	20.33b	2.32a	0.18a	0.12a

[1]Values in the same column of each treatment followed with the same letters were not significantly different at HSD 5%. Fruit firmness on the day of treatment (Day 0) was 4.21 kg/m².
[2]M1: physiologically immature (5th cluster), M2: full mature (3rd cluster), M3: over mature (1st cluster)[11]; C1: non-coating or control, C2: 1% chitosan, C3: 150 ppm GA_3, C4: 1% chitosan + 150 ppm GA_3; S1: room temperature (27 ± 1°C), S2: cold temperature (16 ± 1°C).

Table 2. The Effect of Maturities, Coatings, and Storage on the Fruit °Brix, Acidity, Glucose and Starch[1]. *Source: Author.*

Treatments[2]	**°Brix (%)**	**Acidity (mg/100 g)**	**Glucose (mg/100 mg)**	**Starch (mg/100 g)**
Maturities				
M1	18.72a	0.75a	6.24a	22.87a
M2	18.27a	0.60b	5.78a	19.46b
M3	18.09a	0.57b	5.77a	19.44b
Coatings				
C1	18.78a	0.68a	6.32a	21.12a
C2	18.78a	0.65a	6.17a	20.63a
C3	18.06a	0.64a	5.80a	20.56a
C4	17.81a	0.59a	5.41a	20.06a
Storage				
S1	18.97a	0.76a	6.28a	22.51a
S2	17.75a	0.52a	5.58a	18.68b
Maturities* Coatings				
M2 C2	16.82a	0.59ab	5.41a	18.72b
M1 C1	19.82a	0.59ab	6.40a	18.83b
M1 C2	18.07a	0.54ab	5.37a	19.42b
M2 C1	18.67a	0.50b	6.31a	18.92b
M2 C3	19.67a	0.50b	5.07a	20.86ab
M1 C3	18.47a	0.69ab	5.74a	18.94b
M1 C4	16.70a	0.58ab	5.59a	20.66b
M2 C4	19.70a	0.69ab	6.30a	19.28b
M3 C1	17.85a	0.96a	5.81a	22.42ab
M3 C4	17.02a	0.67ab	7.07a	23.43a
M3 C2	19.27a	0.63ab	6.63a	23.55a
M3 C3	18.20a	0.73ab	5.44a	22.09ab
Maturities* Storage				
M2 S2	16.62b	0.52b	5.60ab	18.78b
M1 S2	17.57ab	0.56b	5.51ab	18.83b
M3 S2	19.05ab	0.49b	7.72a	18.42b
M1 S1	18.96ab	0.64b	6.04ab	20.09b
M2 S1	20.81a	0.62b	5.94ab	20.11b
M3 S1	17.12ab	1.01a	4.75b	27.33a
Coatings* Storage				
C1 S2	17.93a	0.43c	6.56a	18.37c
C2 S2	19.03a	0.52bc	5.93a	18.83bc
C4 S2	17.05a	0.55bc	7.15a	18.88bc
C3 S2	16.98a	0.59bc	5.47a	18.63c
C2 S1	17.08a	0.65abc	5.68a	22.30a
C1 S1	19.63a	0.94a	5.78a	21.74ab
C3 S1	20.58a	0.69abc	5.35a	22.63a
C4 S1	18.57a	0.75ab	5.49a	23.37a

[1 and 2]See Table 1. Fruit °Brix, acidity, glucose and starch in day 0 storage were 13.97%, 0.65 mg/100 g, 2.90 mg/100 g, and 28.47 mg/100 g.

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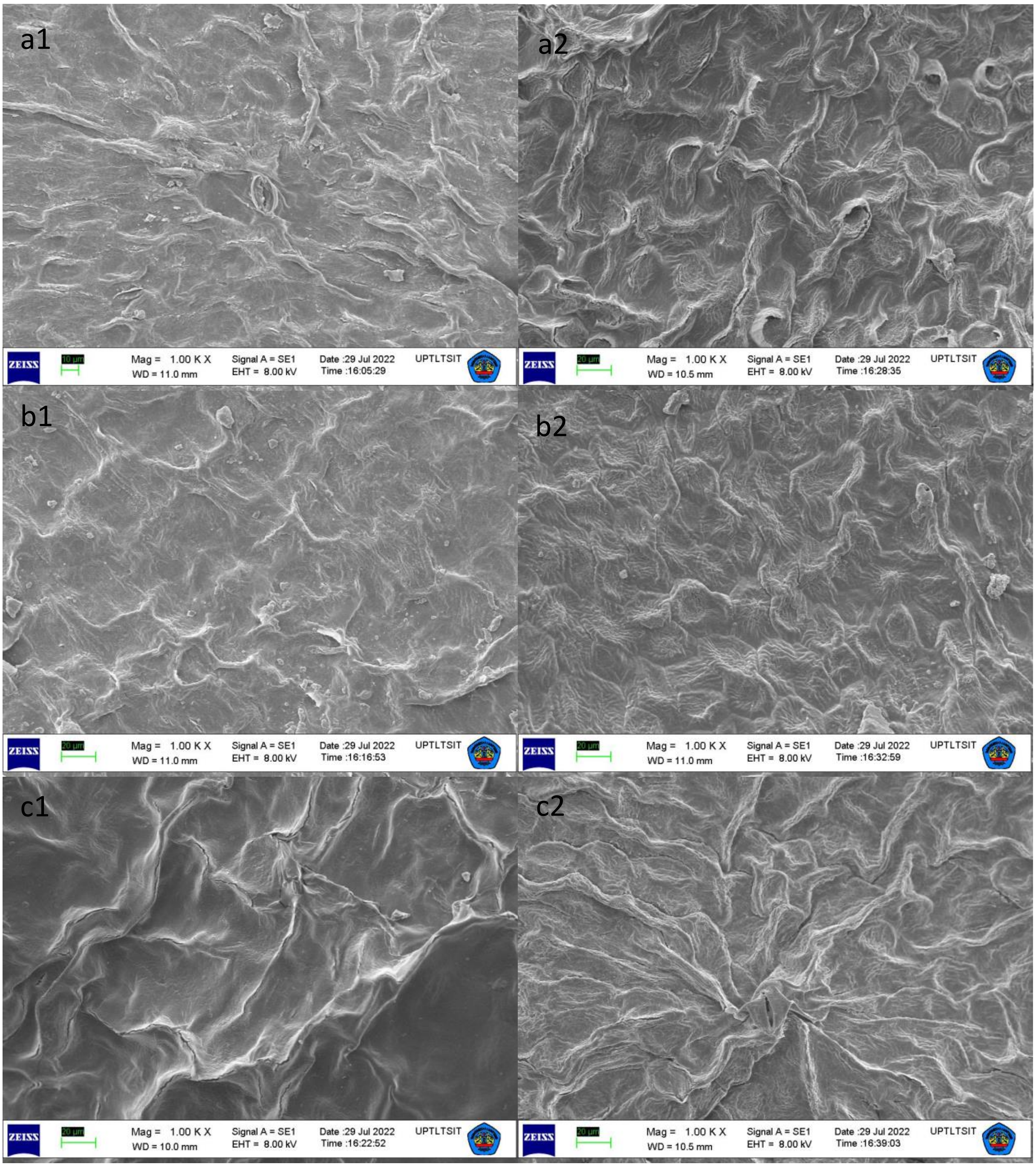

Figure 1. SEM Analyses on Cavendish banana finger rind tips and bases with SEM 1000x magnification. Banana finger rind tips and bases of 5th cluster from the top of the bunch (a1) and (a2), 3rd cluster from the top of the bunch (b1) and (b2), 1st cluster from the top of the bunch (c1) and (c2). *Source: Author.*

Impact

The harvest time of Cavendish banana for export determines its shelf life and quality. This information can support farmers in determining the target market for each cluster, thereby positively impacting their economic condition. Furthermore, when the cluster is not physiologically mature or over-mature, it can cause enormous losses and reduce the country's income due to rejection at the export destination. Post-harvest treatment with maturity level at the third cluster of the bunch (full physiological maturity) combined with cold temperature treatment (M2S2) can be recommended to all Cavendish banana farmers due to its long shelf life with an average of 34.75 days. The use of only chitosan coating is environmentally friendly so that it is safety to apply, but it had no effect on the shelf life compared to the control. This indicates that it must be combined with cold treatment to extend the green-life of Cavendish banana. Low-temperature treatment is very common for post-harvest products because it is very easy to apply and produces profitable results. SEM observations can be carried out at higher concentrations of chitosan and at full coverage to get a perfect coating appearance. The observation showed the effectiveness and help farmers to mitigate the risk of washed coating on the fruit surface.

Conclusions

The application of maturities significantly lengthened the shelf life as well as detained the firmness, diameter, acidity, and starch content. However, it did not reduce weight loss and had no effect on °Brix and glucose content. The results of the application of 1% chitosan, GA_3 150 ppm, or their combination on fruit rind tip and base were not different from the control and had no effect on all parameters. The results showed that a low storage temperature of 16 ± 1°C was able to delay senescence, promote starch degradation, as well as detain firmness and diameter. The combined application of maturities and storage affected all parameters of observations, while maturities and coatings, as well as coatings and storage only influenced the firmness, acidity, and starch content. The SEM analysis of the 1% chitosan coating showed that it fully covered the tip finger rind, but there are some crack points on the base on M1. It also revealed full cover on M2, and some crack points on M3.

Conflict of Interest

There are no conflicts to declare.

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PINEAPPLE RESPONSES TO POSTHARVEST APPLICATIONS OF ABA, CHITOSAN, AND DECROWNING ON THE SEVERITY OF INTERNAL BROWNING AND OTHER FRUIT QUALITIES

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Highlight

Postharvest applications of ABA, chitosan, and decrowning on pineapple internal browning.

Abstract

The shelf life of pineapple is significantly influenced by storage temperature and can be prolonged by maintaining an optimal temperature range of 5-12°C. However, there is still the problem of internal browning (IB) in the long-term storing of fresh harvest at cold temperatures. Postharvest application of 380 µM ABA (Abscisic Acid) to the crown, which is a source of ABA endogenous was found to suppress IB, while the concentration of 95 µM was not effective. Therefore, this research aimed to determine the response of GP3 and MD2 clones to postharvest treatment with the application of 50 mg/L ABA, chitosan and decrowning on the IB severity and other fruit qualities. The experimental design used a Completely Randomized Design with 3 factors of clone (GP3 and MD2), decrowning (crown and crownless), and fruit coating [chitosan 1%, ABA 50 mg/L, ABA + chitosan mix, and control (H_2O)]. The fruits were kept at 7ºC and observed at 0, 3, 6, 9, 16, 23, 30, and 37 days. The results showed that MD2 was significantly lower IB than GP3 and IB severity negatively correlated with ascorbic acid (AsA) content. MD2 had lower fruit weight loss (FWL) and skin dehydration (SD), higher AsA, soluble solid content (SSC), and SSC/titratable acidity (STA) ratios compared to GP3. The crown + ABA treatment decreased the IB severity of GP3, with a level of 0.75% after 37 days which was lower than crown + H_2O by 9.17% and crownless + H2O by 8.42%. ABA treatment also showed higher SD and FWL, while AsA, SSC, TA, and STA were not different from the control.

Keywords

pineapple; postharvest; internal browning; ascorbic acid.

Introduction

According to a survey conducted in 2019, Indonesia is the fourth-largest producer of pineapple globally, following Costa Rica, the Philippines, and Brazil, with a total output of 2,196,456 tons [1]. This is due to pineapple being one of the main agricultural products in the country. However, the issue of internal browning (IB) is particularly important in the global pineapple industry as it can lead to substantial losses during canning and after shipping in refrigerated ocean containers. For example, the Australian pineapple industry incurs losses of US$1.3 million annually due to IB, out of a total production value of around US$30 million [2]. GP3 pineapple clone is a type of

Smooth Cayenne pineapple, while MD2 is a hybrid product that has 50% of the same characteristics as the clone type. Some of the advantages of the MD2 pineapple clone compared to others include its attractive skin colour and ripe fruit (golden yellow), with a higher content of vitamin C, total soluble solids, and resistance to cold storage [3]. Furthermore, its cultivar is more resistant to IB occurrence compared to the Smooth Cayenne cultivar [4,5]. The resistance of Smooth Cayenne to IB during storage of export pineapples has been surpassed by that of the hybrid pineapple. MD2 cultivar helps consumers to consume fresh products in non-tropical countries which can only enjoy canned pineapple preparations from the cultivar Smooth Cayenne[3].

According to a previous report [5], IB severity on MD2 is smaller than Smooth Cayenne cultivars due to its resistance to IB induction [6]. Generally, the initiation of IB occurs through an enzymatic reaction mechanism that depends on the enzyme activity of phenolic compounds, polyphenol oxidase (PPO) and peroxidase (POD), as well as O_2. Browning occurs due to the reaction between oxidized phenolic compounds in the presence of PPO and/or POD enzymes that form highly reactive o-quinones to combine with their counterparts or other phenolic compounds [7]. Meanwhile, symptoms occur in the flesh of the fruit close to the core with the initial appearance of translucent flesh [8]. These symptoms develop with changes in colour to brown and black, which occurs internally without any external signs of the fruit [9]. In the experiment on the crowned and uncrowned pineapples, the highest content of gibberellic acid (GA) was found in the uncrowned fruit. This indicated that the crown was one of the media translocating abscisic acid (ABA) in pineapple and antagonistic to GA. It was also discovered that crowned pineapple fruit with a maturity level of 70% had a positive correlation with an increase in the incidence of IB, GA content, reactive oxygen species (ROS), malondialdehyde (MDA), phenolic content, phenylalanine ammonia-lyase (PAL), and soluble solid content/fatty acid ratios (SFA) [10]. Meanwhile, there was no relationship with PPO activity in pineapple after 9 days of storage at 20°C. Research on ABA infiltration was carried out by spraying its solution on pineapples to determine the severity of IB and GA levels. The results showed that 380 µM ABA reduced the severity of IB and GA after 9 days of storage, as well as PPO after 6 days. while 95 µM had no significant effect [11]. It was also discovered that the combined treatment of 200 mg/L ABA and storage temperature of 5°C can reduce the severity of IB and GA4 [12].

The severity of IB after storing the IB-susceptible variety (Trad-See-Thong) at 10°C started on the 10th day of storage and accelerated on the 8th day after being transferred to 25°C for a day. In the IB tolerant cultivar (Pattavia), the severity started after 19 days of storage at 10°C and accelerated to 15 days after being transferred to 25°C for a day [13]. Long storage at cold temperatures has been found to initiate IB, while wax treatment can reduce the incidence by 87.5% at day 20 [14]. The incidence of IB was reported in several pineapple cultivars in Malaysia, such as Mauritius, Sarawak, Gandol, Babagon, and Maspine. The results showed that Mauritius cultivars previously stored at 8°C and 12°C for up to 4 weeks followed by a week-long storage period at 28°C can induce IB events [15]. Moreover, chitosan is a linear polysaccharide consisting of the monomers N-acetylglucosamine and D-glucosamine with the molecular formula $[(C_6H_{11}NO_4)_n]$. It is widely used in extending the shelf life of fruit by suppressing respiration rates, such as guava fruit as reported by [16], bananas [17,18], strawberries [19], and avocados [20]. Chitosan coating was also developed to maintain shelf quality (ascorbic acid (AsA), total phenol, and antioxidant activity) and extend the shelf life of strawberries and apples [21].

The content of AsA in pineapple will affect resistance to IB. This is because the higher the AsA content, the lower the physiological damage to IB. The suppressing activity is related to that of AsA compounds as antioxidants (acidification and chelating of PPO enzymes) and ROS scavengers in protecting cells from damage [7,22–25], AsA content in pineapple also has a negative correlation with IB physiological damage and PPO enzyme activity [7,10–12,26–28]. The application of postharvest treatment can decrease IB severity in fresh pineapple in a short and effective time, which makes it applicable to the large pineapple industry. According to and [10,11], spray treatment by immersing pineapple fruit in 50 mg/L ABA solution will successfully reduce IB severity. It was discovered that a recommended concentration, lower than 380 µM and an optimum temperature provided a more efficient and effective effect, without reducing fruit qualities. The effect of chitosan is also expected to reduce O_2 in preventing aerobic conditions to suppress the browning enzymatic reaction. Therefore, the combination of both postharvest application of ABA and chitosan on crowned and decrowned pineapples in this research will have a significant impact in reducing the IB severity. It is also expected that GP3 pineapple clone will balance the fruit's resistance to meet exportation requirements.

Methods

This research was conducted at Great Giant Food Co. Ltd. (GGF), East Lampung, Lampung, Indonesia, in August

September 2022. Fresh pineapple was harvested from GGF with a weight of 825-1,124 g/fruit and an export standard maturity level with a yellow skin colour of 0%. The experiment used a 2 x 2 x 4 factorial in a Completely Randomized Design. The 3 factors were clones (GP3 and MD2), Decrowning (Crown and Crownless), Coating [(chitosan [$(C_6H_{11}NO_4)_n$] 1%, Abscisic Acid (ABA) [($C_{15}H_{20}O_4$) Phytotechlab, Lenexa, Kansas, USA] 50 mg/L, ABA 50 mg/L + chitosan 1% mix, and control (H_2O)]. Both destructive and non-destructive observations were made 7 times on days 3, 6, 9, 16, 23, 30, and 37 with 3 replicates. The application of H_2O and chitosan treatment was carried out by soaking the fruit in H_2O and single chitosan. Subsequently, ABA and the combination of ABA + chitosan were applied by spraying their solution until the entire surface of the fruit was wet. In the ABA + chitosan treatment, the fruit was first sprayed with ABA, and dried for 30 minutes, followed by the application of chitosan. Pineapple fruit was air-dried for 30 minutes before being packaged in cardboard with a capacity of 10-11 sheets per carton that has been perforated (GGF packaging cardboard). All fruits were stored at 7°C for 37 days.

The destructive and non-destructive characteristics were observed. The destructive variables included:

a. the IB severity, which was measured using the fruit score, by observing the surface area of the transverse fruit pieces experiencing a change in colour from transparent to blackish brown. Meanwhile, a score of 1 indicated mild category (< 5%), 2 was moderate (6-10%), 3 was moderately severe (11-20%), and 4 weight categories (> 20%), with the formula:

$$\text{IB severity (\%)} = [(\Sigma \text{ no. of the IB in category x category value})/(\text{total no. of fruits x the highest category value})] \times 100\% \quad (1)$$

The scoring of IB severity was based on the United States Standards for Grades of Pineapples with modification [29].

b. AsA was determined using the titrimetric approach outlined in AOAC Method 967.21 [30]. This involved adding 2 ml pineapple juice or AsA (as Dye factor), with 5 ml of metaphosphoric acid (HPO3), and shaking until homogeneous. The solution was titrated using 2,6-dichlorophenol indophenol (2,6-D). The AsA value was calculated by the formula:

$$\text{AsA (ppm)} = [(\Sigma \text{ actual 2,6-D volume x Dye-factor})/(\text{sample volume})] \times 1000 \quad (2)$$

c. Soluble solid content (SSC) was measured by dropping fruit juice on a digital refractometer prism glass and the value obtained was expressed in the Brix value.

d. Titratable Acidity (TA) was measured by mixing 5 ml of fruit juice with 5 drops of phenolphthalein indicator, which was shaken until homogeneous. The solution was titrated using 1 N NaOH compound and the TA value was calculated by the formula:

$$\text{TA (\%)} = [(\Sigma \text{ NaOH volume x 0.064 x NaOH molarity})/(\text{sample volume})] \times 100\% \quad (3)$$

e. and SSC/TA ratio (STA), the comparison between SSC and TA values. Non-destructive observation variables include:

   - Fruit weight loss (FWL), which was determined by weighing the fresh weight on the daily observation and the initial weight with a digital scale. The FWL value was calculated by the formula:

$$\text{FWL (\%)} = [(\Sigma \text{ Weight on the day of observation – the initial weight})/(\text{weight from the initial weight})] \times 100\% \quad (4)$$

Furthermore,

   - Dehydration of the fruit skin was determined by scoring 10 samples around the open eyeball on each of the 3 sides of the fruit. The degree of shrinkage level was indicated by score, where a score of 1 represented the mild (<25%), 2 was moderate (26-50%), and 3 was in the heavy category (>26%). The fruit was calculated for the severity of skin dehydration (SD) with the formula:

$$\text{SD (\%)} = [(\Sigma \text{ no. of the skin around the eye in the category x category value})/(\text{total no. of skin eyes x the highest category value})] \times 100\% \quad (5)$$

The data were processed by comparing the mean with the 95% confidence interval (mean±CI) (α=0.05) for each treatment group and post hoc. test with Duncan's Multiple Distance Test (DMRT). Data were displayed on bar and line charts with CI bars and tables as well as letter notation to compare their significance. Statistical data were processed using the IBM SPSS Statistics Version 26 program.

Results and discussion

The experiment with pineapple clones gave different responses to long shelf life at 7°C for 37 days on the IB severity. The results showed that MD2 clone was more resistant, as evidenced by its 1.40% (mild symptoms) IB severity compared to the 11.63% (moderately severe) in GP3 on day 37, as presented in Figure 1.A. MD2 pineapple cultivar also had higher resistance than Smooth Cayenne cultivars [5]. It was also discovered that when the fruit was stored at 7°C for a shelf life of 23 days, the IB began to occur, but there was no incidence of IB for 16 days of storage and below.

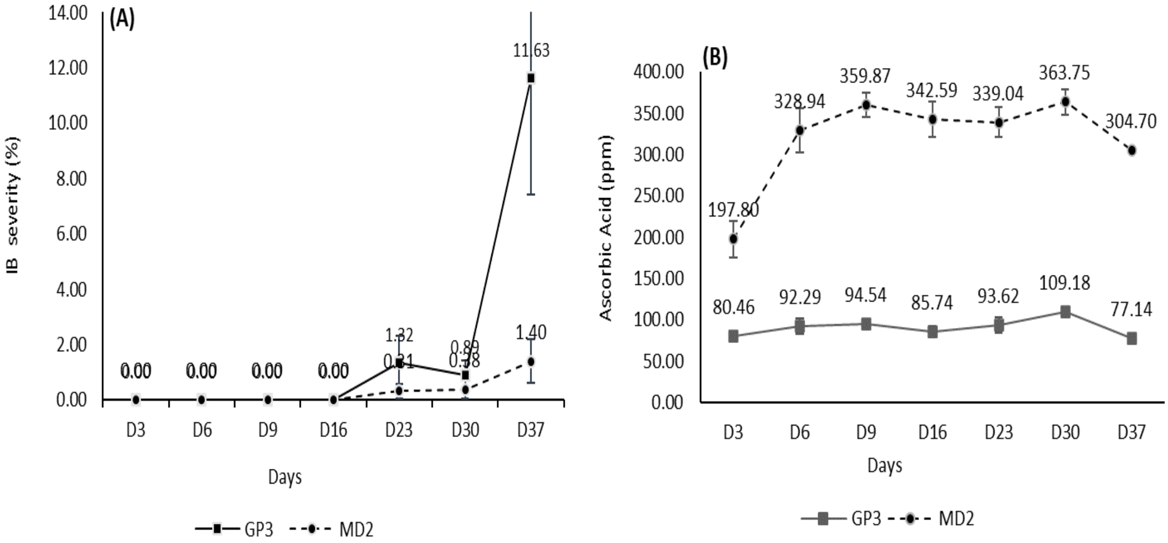

Figure 1. Comparative response between the development of GP3 and MD2 clones stored at 7°C for 37 days on the IB severity (A) and ascorbic acid (B). The values are mean±CI. *Source: Author.*

There was a significant difference in AsA content, where MD2 clone had higher values than GP3 as presented in Figure 1.B, which negatively correlated with the IB severity on day 37 in Figure 1.A. AsA has been shown to decrease the activity of the PPO enzyme, thereby reducing the IB severity [7,10–12,26–28]. According to [31], there was no correlation between AsA content and IB severity, which was also reported in GP3 pineapple clone. It was also discovered that the genetic factors of pineapples have a considerable influence on IB severity [6]. This is in line with a previous study, where the pineapple sclerenchyma cultivar MD2 observed using scanning electron microscopy had a thicker sclerenchyma fibre layer structure and was twice as large as susceptible cultivars (Trad-See-Thong). Furthermore, the tolerant (Pattavia) of IB, MD2 sclerenchyma cells formed concentric rings around the phloem and xylem. Based on this research, it was concluded that ASA can suppress IB severity when its content in pineapple fruit is above or equal to 197.80 ppm.

All treatments of MD2 clone showed no significant difference in the IB severity. However, in GP3 clone, the interaction of crown and ABA 50 mg/L was significant compared to other treatment interactions. This did not include GP3 x Crownless x Chitosan treatment, because it had an insignificant effect compared to others, as illustrated in Figure 2.A. The application of ABA treatment in GP3 pineapple clone with crown intact was included in the mild category, and the others were moderate, except for the combination of ABA and Chitosan. This treatment can be used as in reducing the IB severity at a temperature of 7°C up to a shelf life of 37 days. Generally, the crown is a source of exogenous ABA in pineapple, which contributes to donors, and is antagonistic to GA compounds. Gibrelic acid (GA) endogenous in pineapple has a positive correlation with IB severity [10–12].

There was no significant difference between the treatment of decrowning and clones on AsA levels, as illustrated in Figure 2.B. This experiment concluded that AsA was formed by the respective genetic clones (GP3 and MD2).

According to a previous report [9], the decrowning was not correlated with AsA content. The IB severity was not correlated with AsA, while the IB-tolerant Pattavia cultivar had lower AsA content than the Trad-See-Thong cultivar [31].

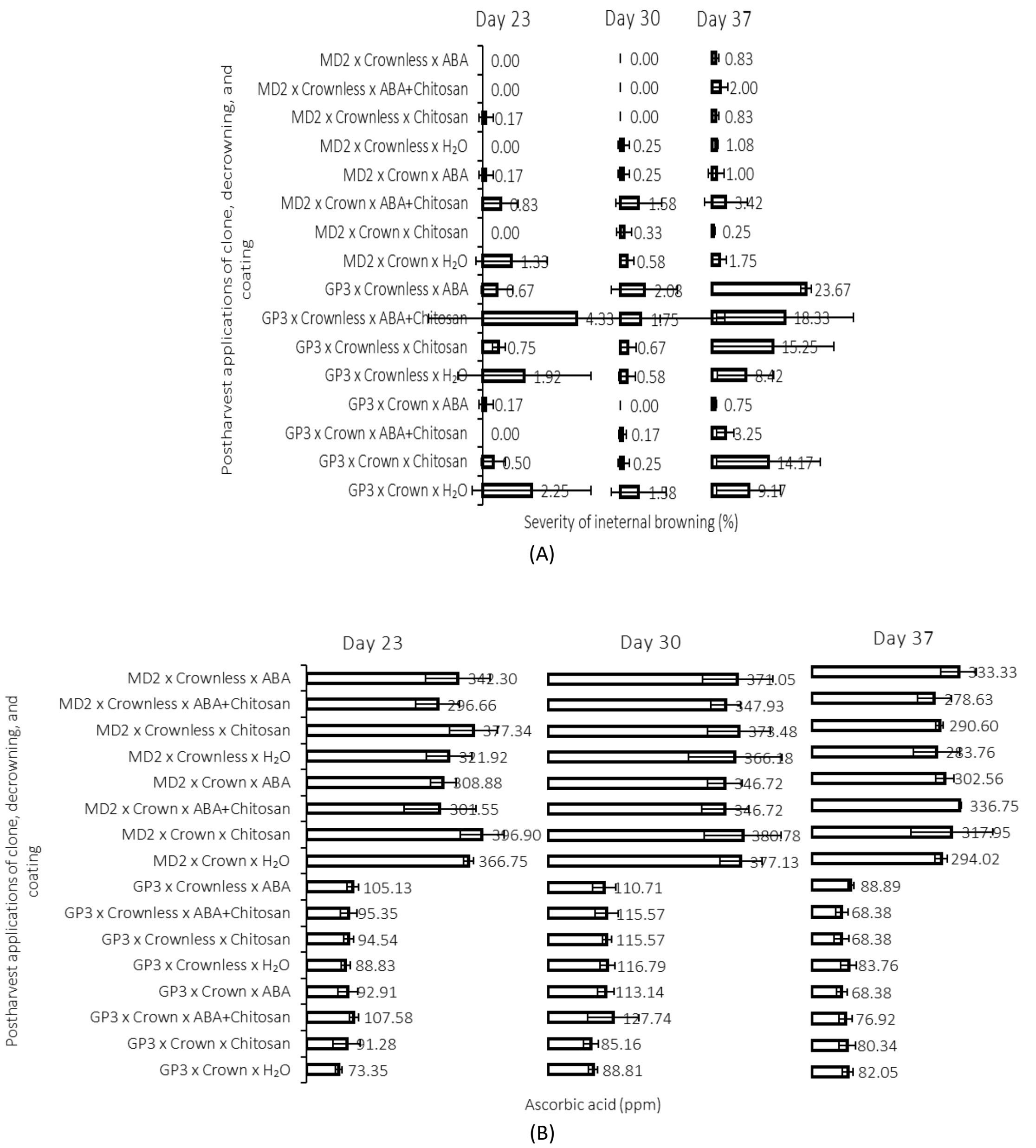

Figure 2. Response of GP3 and MD2 pineapple clones to postharvest applications of ABA, chitosan, and decrowning on the development of IB severity (A) and ascorbic acid (B) stored at 7°C for 37 days. The values are mean±CI. *Source: Author.*

Pineapple decrowning did not significantly affect the occurrence of IB in MD2 and GP3 clones. However, [10] stated that decrowning can exacerbate damage due to IB in Queen types of pineapple. Based on data on the level of ripeness used, the 0% maturity level used in this research was different from [10] which applied 70% after treatment. This showed that the response to IB severity will be varied due to different in maturity levels and cultivar types of pineapple. The 50 mg/L ABA can suppress IB in GP3 pineapples with intact crowns (Smooth Cayenne type). This is in line with [10,11], where postharvest treatment of 380 uM ABA suppressed the occurrence of IB in pineapple cultivars Pattavia (Smooth Cayenne type) and Trad-See-Thong (Queen type). The 50 mg/L ABA is almost the same as the 190 uM, therefore, it has half effect of the 380 uM concentration.

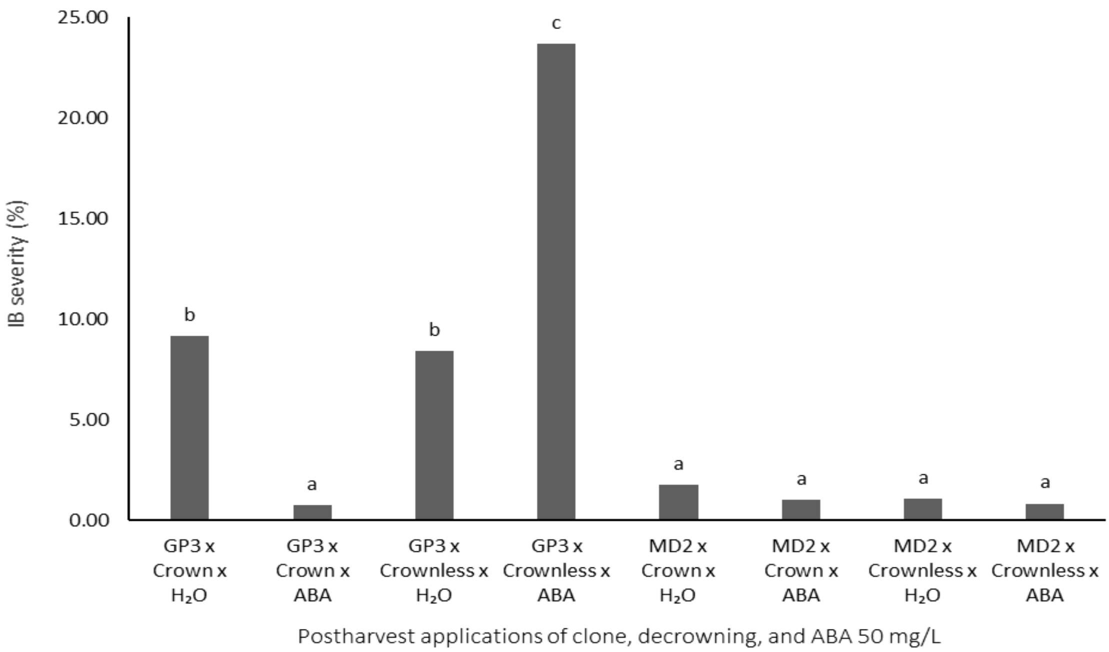

Figure 3. Effect of pineapple clones, decrowning, and 50 mg/L ABA application on IB severity stored at 7°C for 37 days. Lowercase letters indicate statistically significant differences by DMRT ($p \leq 0.05$). *Source: Author.*

The high levels of AsA value in MD2 clone showed a positive correlation in decreasing the IB severity. This can be a reference for the AsA compound infiltration experiment in IB severity reduction in GP3 or others. The increase in endogenous AsA can be obtained from the combination treatment of the application of AsA or isoascorbic acid (IAA) and plastic bagging on pineapple slices in decreasing the IB severity [32]. The application of methyl jasmonate (MJ) can prevent a reduction in AsA content in pineapple storage on PPO activity, incidence, and IB severity [28].

The application of postharvest ABA in GP3 pineapple with crown intact was not significant compared to the ABA treatment and the control in MD2 clone on the IB severity. However, it had a significant effect on other GP3 treatments during 37 days of storage as shown in Figure 3. This treatment had the same resistance as MD2 clone with a fairly high AsA content. According to [10], the crown and ABA treatment as a source of endogenous ABA in decreasing GA and phenolic biosynthesis can decrease the IB of pineapple. It was also discovered that crown and ABA treatment in pineapple storage decreased GA biosynthesis [8], phenolics compound, PAL activity [11], and PPO activity [12] compared to crownless treatment.

Table. 1. Effect of pineapple clone, decrowning, and ABA 50 mg/L application on fruit qualities stored at 7°C for 37 days. *Source: Author.*

Treatment	**SSC (%)**	**TA (%)**	**STA**	**FWL (%)**	**SD (%)**
GP3 x Crown x H_2O	12.03abc	0.49ab	24.82a	13.40e	28.87a
GP3 x Crown x ABA	10.77a	0.37ab	29.75abc	14.17e	34.85bc
GP3 x Crownless x H_2O	11.33ab	0.55b	20.92a	10.27cd	28.52a
GP3 x Crownless x ABA	12.30abc	0.47ab	26.27ab	10.77d	37.11c
MD2 x Crown x H_2O	13.03abcd	0.34a	39.71c	9.52bc	31.16ab
MD2 x Crown x ABA	14.90cd	0.51ab	29.69abc	10.10cd	32.86b
MD2 x Crownless x H_2O	16.40d	0.45ab	37.66bc	7.14a	27.82a
MD2 x Crownless x ABA	14.40bcd	0.50ab	29.49abc	8.44b	34.48bc

[1]Lowercase letters indicate statistically significant differences by DMRT ($p \leq 0.05$).

GP3 x Crown x ABA treatment at a shelf life of 37 days at 7°C had no significance in SSC compared to others. However, it was lower than all MD2 treatments except for the Crown x H_2O treatment. TA and Sweetness levels

(STA) in GP3 x Crown x ABA treatment were not significantly different in all treatments, but weight loss was higher except for GP3 x Crown x H_2O treatment. Skin dehydration (SD) was higher than the control in GP3 and MD2 clones, except for MD2 x Crownless x H_2O treatment as presented in Table 1. According to a previous report [11], the ABA 380 µM exogenous treatment was not significant compared to the H_2O treatment on SSC.

Impact

MD2 pineapple had a high AsA content, therefore, it can reduce the IB severity at a storage temperature of 7°C for 37 days. This showed that MD2 clone did not need additional postharvest applications other than fruit storage at 7°C. Moreover, decrowning in pineapple storage efficiency can be carried out on MD2 clone to reduce packing costs, increase storage and transportation capacity. In pineapples with low AsA content such as GP3 clone which only ranged from 73.35 – 127.74 ppm, IB severity for 37 days at 7°C can be reduced by applying a postharvest treatment of 50 mg ABA coating /L with the crown intact. Through this method, GP3 clone that only met the demand for processed canned pineapple can be increased due to the demand for fresh pineapple to replace MD2. By applying specific recommendations for pineapple clones, yield losses during long-term storage, namely 37 days at a temperature of 7°C against IB damage, can be reduced effectively and efficiently.

Conclusions

The results showed that the MD2 clone had higher resistance compared to GP3 because the AsA content positively correlated to decreased IB severity. ABA treatment with the intact crown on GP3 clone had a significant effect on IB severity compared to control (H_2O) on crowned or decrowned pineapples. ABA treatment on fruit with intact crowns also maintained fruit quality, such as AsA, soluble solids content (SSC), titratable acidity (TA), and SSC/TA ratios (STA) but had higher fruit weight loss and skin dehydration. Therefore, by maintaining the integrity of the crown on GP3 clone stored at 7°C for 37 days, ABA treatment can be used as a reference in reducing the IB severity.

Conflict of interest

There are no conflicts to declare.

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IMPACT OF ECONOMETRIC MODELING AND PERSPECTIVES OF ECONOMIC SECURITY OF THE CROSS-INDUSTRY COMPLEX

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Highlight

Econometric modeling and forecasting of the economic security of an interdisciplinary complex describe the connections between economic variables and objects.

Abstract

The paper presents a forecast of the economic security of the inter-industry complex through the construction of a simulation model. The authors considered the possibility of using an econometric model in predicting the level of economic security of the inter-industry complex. The goal was to form a definition of the "inter-industry complex", as well as to study the issues of conceptual and fundamental methods of econometric modeling and forecasting the development of regional industry markets in dynamics. A range of issues related to the main components of economic security in the inter-industry complex has been allocated for scientific work in order to analyze the impact of the components of economic security on the integral indicator. The paper uses a methodology for predicting the structural and spatial-temporal dynamics of interbranch complexes, which includes new and refined methods of modeling and forecasting. As a result, the authors proposed the definition of "inter-industry complex", "economic security in the inter-industry complex", as well as the general provisions of the methodology for econometric modeling and forecasting the level of economic security of the inter-industry complex. The paper presents a full-scale simulation model that allows you to set, evaluate and make a decision using large nonlinear data. This kind of system contains dynamic and retarded data, which makes it possible to apply econometric modeling in automatic calculation.

Keywords
economic security; intersectoral complex; econometric model; forecasting.

Introduction

Industry is considered one of the main structures of the economic complex of all developed and developing modern states. It includes, as a rule, many enterprises, industries of various industries that provide the extraction and processing of natural resources, the production of various products both for the needs of the industry itself and for other areas of human activity. In the analysis of the state of industry, special attention should be paid to the study of the functioning of intersectoral complexes, which are presented in works [1–3] in a certain way interconnected, interacting, and also complementing each other's activities with industrial sectors and industries [4,5]. An intersectoral complex is a special structure for the integration and interaction of one or more industries. Such a structure can be built in one industry segment and allocated in accordance with the division of labor. So, within the segment, machine-building, fuel and energy and other inter-industry complexes can be distinguished [6]. At present, the former types of organizational structures of economic entities are not effective enough, as a result of which there is a need to create new, modern types of organizational structures. An example of these types are network structures, which are now becoming a feature of the new economy. The network approach is considered in [7–10]. As a result, complex interactive relationships develop that connect the resources and activities of one party with the resources and activities of the other. It should be noted that in addition to the above reasons, the transition from the industry level to the network level is due to the principles of the fourth industrial revolution, which consider the network organization of production as a network, that is, when the boundaries between enterprises and even industries (types of economic activity) are erased, and the production process itself is considered like a network. Against this background, the topic of economic security of both the national economy and industries, as well as individual enterprises, is becoming increasingly relevant. It should be noted that the security of business structures is the basis for maintaining stable competitive positions, a prerequisite for the effective functioning and stable development of business entities. Based on the conducted research, it was established that the main negative factors in ensuring the proper level of economic security of enterprises are the following: lack of effective functioning of the market environment; incomplete formation of the institutional base of economic policy; imbalance of state regulatory policy; imperfection of budget policy; abuse of a monopoly price position; an increase in the number of criminal offenses, so-called "raiding", corruption and discriminatory actions regarding the specifics of the work of regional enterprises; the imperfection of the judicial system, the corruption of authorities and the absence of state institutions that would effectively protect the rights of the owner; low level of competitiveness of enterprises and their innovative activity; unsatisfactory indicators of the financial condition and efficiency of the functioning of enterprises and their use of resource provision, etc. As a result of the analysis, we note that the economic security of enterprises should be understood as the state of protection of its resources and intellectual potential from existing and potential threats of the external and internal environment of its functioning, which is characterized by high financial indicators of activity and the perspective of economic development in the future. Continuing the logic of our research, we should pay attention to the fact that network value chain analysis provides insight into the structure of the production process to identify areas where efficiency can be improved, thereby enhancing the efficiency of industrial complexes and strengthening their economic security.

The process of econometric modeling and forecasting of economic security includes several stages:

- At the first stage, it is necessary to set a meaningful goal and formulate research objectives. The purpose of the study is to assess the degree of influence of factors of the external and internal environment and the results of ensuring the economic security of the intersectoral complex.
- At the second stage, an econometric model is built. Therefore, in order to effectively ensure the economic security of the intersectoral complex, it is necessary to conduct a comprehensive analysis of the economic security of an enterprise based on an analysis of the total set of threats.

On Figure 1 shows the internal and external components of the cumulative assessment of economic security (ES) of intersectoral complexes (IC).

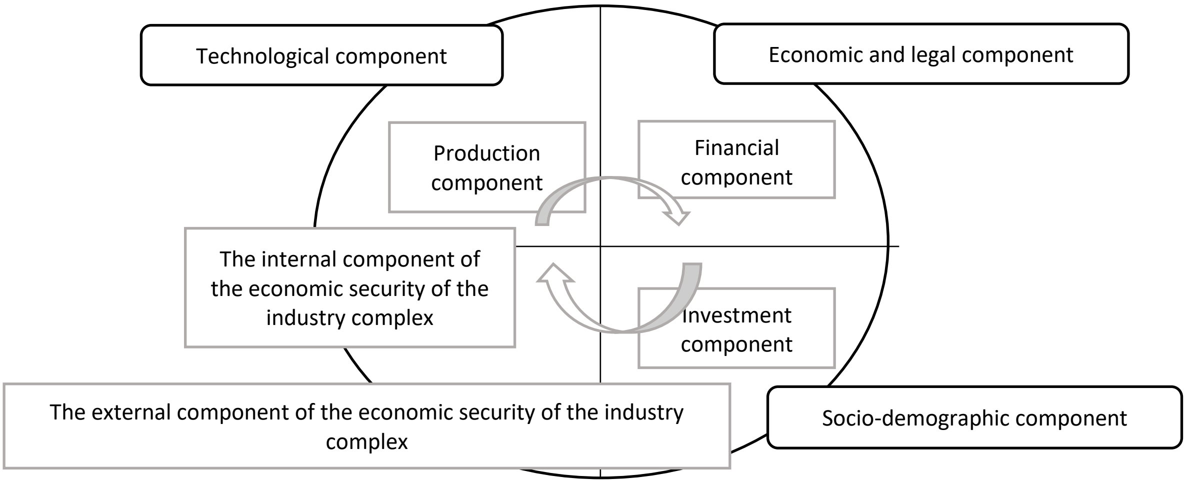

Figure 1. Aggregate Assessment of Economic Security of Intersectoral Complexes: Internal and External Components. *Source: Authors development.*

Methods

The level of economic security of enterprises is characterized by many indicators. The assessment of the state of economic security of enterprises is carried out through a system of criteria and indicators. The criterion of economic security of the enterprise is a measure of the state of the economic entity from the point of view of compliance of the actually achieved indicators of its activity with pre-established indicators that reflect the essence of economic security. In this case, the general task of forming an assessment of the economic security of the system is to develop such an assessment, with the help of which the threat of the destruction of the system is quantitatively detected during the operation of the system in order to take measures to prevent this in a timely manner. Such an estimate can be obtained using the parameters of the system motion trajectory in the form of a functional:

(1) $$J_S = J_S(t, s, u, \sigma, \varepsilon), s\hat{I}\,S, u\hat{I}\,U, s\,\hat{I}\,å, e\,\hat{I}\,X$$

where:
J_S - safety indicator
t - time
s – state
u - management
σ - the influence of the environment
ε - internal disturbance.

The schematic diagram of the formation of the Jb safety indicator based on all information flows in the system is shown in Figure 2.

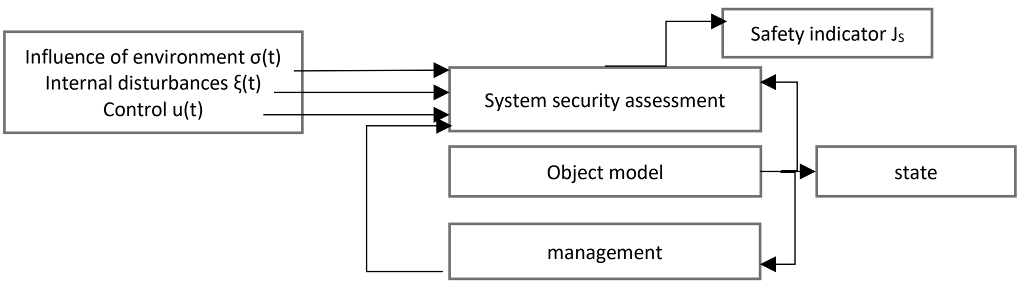

Figure 2. A typical logical scheme for forming an assessment of the economic security of an enterprise. *Source: Authors development.*

A comprehensive assessment of economic security can be represented as a function that includes the internal component of the ES IC: production, financial, investment, and the external component of the ES IC: technological, socio-demographic and economic and legal, which, in turn, are also divided into components indicators:

(2) $$C_{IN.C.} = \int(C_P, C_F, C_I)$$

where:
$C_{IN.C.}$- economic related industries; internal component security
C_P - production component of network associated industries
C_F - financial component of network related industries
C_I - investment component of network related industries.

At the same time:

(3) $$C_{EX.C.} = \int(C_{E\&L}, C_T, C_{S-D})$$

where:
$C_{EX.C.}$- external component of the security of network related industries
$C_{E\&L}$ - economic and legal component of network related industries
C_T - technological component of network related industries
C_{S-D} - socio-demographic component of network related industries.

It should be noted that the data for calculating the component can be expanded. Our choice stopped due to on the availability data on the indicators on the website of state statistics. In addition, these indicators can be tracked in dynamics, which will make it possible to calculate the level of economic security and analyze its dynamic change. It should also be clarified that indicators by type of network production can vary significantly due to the peculiarities of the functioning of production. That is why we propose to use normalized indicators to calculate the level of economic security. This econometric approach is considered in publications [11–14]. The next stage of econometric modeling is the selection of the necessary indicators for calculating the level of economic security of the intersectoral complex and the programming of the simulation model. Debugging a model involves assessing its adequacy and suitability, as shown by the values of the relevant criteria [15–17]. Examining the data of state statistics (Table 1), we can identify a number of indicators that tend to increase, decrease, and those that do not change in the period 2019–2022.

It should be noted that the data for calculating the component can be expanded. Our choice was based on these indicators due to their availability on the website of the state statistics. These indicators can be tracked in dynamics, which will make it possible to calculate the level of economic security and analyze its dynamic change. It is also necessary to clarify that indicators by type of network production can vary significantly due to the peculiarities of the functioning of production. For this reason, we propose to use normalized indicators to calculate the level of economic security.

The main factor determining the importance of an indicator is its weight. Before the introduction of one or another key risk indicator, its threshold values and limits are developed. Usually, the exponent *x* varies from some minimum value x_{min} (reflecting lack of quality) up to some maximum value x_{max} (extreme degree of manifestation, presence, severity and etc.). As a rule, the value is normalized in the range from 0 to 1.

To do this, the transformation function y = f (x) must have the following properties:

(4) $$y\ (x_{min}) = 0; y\ (x_{max}) = 1; dy/dx > 0$$

Any function with these properties can be used for normalization. For example, if then $x_{max} \to \infty$ you can choose a function:

(5) $$y(x) = 1 - \exp\ (1 - \frac{1}{x_{min}})$$

It is easy to see that, by choosing the appropriate function, one can consider various effects of estimation distortion. According to the methodology, since the indicators used to describe the state of economic security have different units of measurement, they were brought to a single scale using the standardization of values, which allows one to switch to a single dimensionless value. To assess economic security on the basis of the selected features, the entropy method for assessing the sustainability of economic security was adapted, which is considered in papers4 [18,19].

The method makes it possible to decompose the total entropy into components - the entropy of interaction, configuration, local, structural, etc., which makes it possible to develop solutions for their minimization.

Table 1. Initial data for building an econometric model for predicting the economic security of an intersectoral complex. *Source: Compiled by the authors based on state statistics [20].*

Index	**2019**	**2020**	**2021**	**2022**
Initial data for calculating the production component				
Labor productivity index	100.7	97.8	99.8	99.88
Index of change in capital-labor ratio	105.2	104	103.8	105.03
Index of change in capital productivity	96.7	97	93.3	97.37
The coefficient of renewal of fixed assets	4.8	4.6	4.3	4.82
Initial data for calculating the investment component				
Share of investment in fixed assets in gross domestic product	20.5	19.6	20.8	20.15
Increase in the number of high-performance jobs	4.5	-9.1	-4.8	1.52
Innovative activity of organizations (share of organizations that carried out technological, organizational, marketing innovations, in the total number of organizations)	9.9	9.3	8.4	9.95
Share of internal spending on research and development in GDP and GRP	1.07	1.1	1.1	1.08
Initial data for calculating the financial component				
Profitability of organizations (excluding small businesses)	7	7.3	8.1	6.92
Return on assets	4.5	2.5	3.7	3.97
Dynamics of accounts payable of organizations (excluding small businesses)	33 174	38 925	42 280	33 573
Dynamics of receivables of organizations (excluding small businesses)	31 014	35 736	37 053	31 581
Initial data for calculating the technological component				
Production index for high-tech manufacturing economic activities	92.3	103	98.7	94.8
The share of internal costs for research and development in priority areas of development of science, technology and technology, in the total volume of internal costs for research and development	67.9	68.6	71	67.62
Number of advanced manufacturing technologies developed	1 409	1 398	1 534	1 384.5
Number of new technologies (technical achievements), software tools acquired by organizations	28 705	24 361	64 914	21 222
Initial data for calculating the economic and legal component				
Indices of physical volume of gross domestic product	100.7	97.5	99.8	101.5
Volume of loans provided to legal entities	203.84	182.68	188.94	209.43
Number of economic offenses	11.5	11.9	13.2	10
Index of output of goods and services by basic types economic activity	102	97.6	100.5	101.4
Initial data for calculating the socio-demographic component				
Working-age population	75.43	76.59	76.64	76.69
Employment rate	65.3	65.3	65.7	65.7
Unemployment rate	5.2	5.6	5.5	5.5
Average monthly salary	32.6	33.93	36.7	39.09

Results and Discussion

Entropy processes constitute an unshakable system-forming property of the vital activity of systems at any level of organization. Over the last year of a full-scale war, there has been a negative downward trend in investment. The deterioration of the economic situation had a negative impact on the volume of foreign direct investment attracted during the period of martial law. A large number of regional enterprises during the crisis were left without the support of foreign investors, as well as completely / partially destroyed and forced to move their assets to safer territories. At the same time, over the past year, the leading regions of the country also show almost zero dynamics in the development of industry. The fall in prices for the products of basic industries has destabilized industrial safety in general.

Table 2. Calculation of the level of economic security of intersectoral complexes in 2019–2022. *Source: Calculated by the authors.*

Index	**2019**	**2020**	**2021**	**2022**
ES IC of the production component	0.718	0.717	0.714	0.718
Labor productivity index	0.955	0.938	0.960	0.949
Index of change in capital-labor ratio	1	1	1	1
Index of change in capital productivity	0.915	0.93	0.894	0.923
The coefficient of renewal of fixed assets	-	-	-	-
ES IC of the investment component	0.408	0.499	0.437	0.372
Share of investment in fixed assets in GDP	1	1	1	1
Growth in the number of highly productive jobs Innovative activity of organizations (share of organizations that carried out technological, organizational, marketing innovations in the total number of organizations)	0.177	-	-	0.023
Share of internal spending on research and development	0.454	0.641	0.516	0.465
in GDP and GRP	-	0.355	0.23	-
ES IC of the financial component	0.503	0.511	0.495	0.508
Profitability of organizations (excluding small businesses)	0.087	0.132	0.114	0.1
Return on assets	-	-	-	-
Dynamics of accounts payable of organizations (excluding small businesses)	1	1	1	1
Dynamics of receivables of organizations (excluding small businesses)	0.925	0.912	0.865	0.933
ES IC of the technological component	0.508	0.472	0.592	0.48
Production index for high-tech manufacturing economic activities Share of domestic spending on research and development in priority areas of science and technology development	1	1	1	1
and technology, in total domestic research and development spending	0.732	0.661	0.715	0.709
Number of advanced production technologies developed Number of new technologies (technical advances); software tools acquired by organizations	-	-	-	-
Production index for high-tech manufacturing economic activities Share of domestic spending on research and development in priority areas of science and technology development	0.3	0.226	0.652	0.212
ES IC of the economic and legal component	0.484	0.501	0.497	0.479
Indices of physical volume of GDP	0.464	0.501	0.493	0.459
Volume of loans provided to legal entities Number of economic offenses	1	1	1	1
Index of output of goods and services by basic types of economic activity	-	-	-	-
Indices of physical volume of GDP	0.471	0.502	0.497	0.458
ES IC of the socio-demographic component	0.561	0.56	0.571	0.579
Working-age population	1	1	1	1
Employment rate	0.856	0.841	0.846	0.846
Unemployment rate	-	-	-	-
Average monthly salary, thousand rubles	0.39	0.339	0.439	0.472
Internal component of EB MK	0.543	0.576	0.548	0.533
External component of EB MK	0.511	0.511	0.552	0.506
EB MK level	0.53	0.543	0.551	0.523

The country's lag in the innovation sphere is primarily due to the martial law and the continuation of active hostilities in a large area of Ukraine. There is a deterioration in the state of external economic security. The decrease in foreign trade turnover is caused by the deterioration of logistics routes, their blockade by the aggressor and the presence of numerous barriers. The rise in inflation in 2022 was the result of a jump in the hryvnia exchange rate due to changes in the country's GDP and a decrease in the production capacities of enterprises of various levels. The decline in the solvency of Ukrainian organizations led to an increase in overdue accounts payable. These processes had a significant impact on the level of the country's financial security. The unfavorable economic situation also affected the standard of living of the population. There was a decrease in real incomes and, as a result, consumer demand decreased. There was a threat of a decrease in the income of the population and, as a result, the percentage of the average income tends to approach the subsistence level, which leads to impoverishment of the population.

The calculation of entropy indicators shows that throughout the analyzed and forecast period, the entropy indicator characterizes a fairly large influence of production, financial, personnel, investment and environmental factors on the state of economic security of intersectoral complexes. The parameters of the regression equations were calculated by the least squares method using the Statistica program using the data given in Table. 2.

Standard deviations of initial samples data compared to the values of the data themselves are insignificant, that is, the scatter of points small in the samples. Deviations the maximum and minimum values of the samples from the respective medians and the average is also small. Values the coefficient of variation of the samples makes it possible to judge their homogeneity. Accepted points regression equations allow you to apply it for the forecast.

As a result of the calculations, the regression equations of the model were obtained, presented in Table. 3.

Table 3. Regression models of economic security components of sectoral complexes. *Source: Calculated by the authors.*

Model parameters	**Production component of ES IC**	**Investment component of ES IC**	**Financial component of ES IC**
Regression Equation	ES IC_P = -0.0002x+0.717	ES IC_I = -0.017x+0.4713	ES IC_F = -0.0001x+0.5044
Average	0.716506	0.428876	0.504188
Standard error	0.001012	0.026869	0.003595
Median	0.717215	0.422135	0.505528
Standard deviation	0.002025	0.053738	0.007189
Sample variance	$4.1*10^{-6}$	0.002888	$5.17*10^{-5}$
Excess	2.672686	0.469564	-0.06333
Asymmetry	-1.63986	0.664946	-0.87658
Interval	0.00446	0.127023	0.016416
Minimum	0.713568	0.372106	0.494641
Maximum	0.718028	0.499129	0.511057
Sum	2.866026	1.715504	2.016753
Check	4	4	4
Largest (1)	0.718028	0.499129	0.511057
Smallest (1)	0.713568	0.372106	0.494641
Reliability level (95%)	0.003222	0.085509	0.01144
Model parameters	**Technological component of ES IC**	**Economic and legal component of ES IC**	**Socio-demographic component of ES IC**
Regression Equation	ES IC_T = -0.0037x+0.5037	ES $IC_{E\&L}$ = -0.0016x+0.4943	ES IC_{S-D} =0.0065x+0.5518
Average	0.512992	0.490248	0.568022
Standard error	0.027377	0.005215	0.004528
Median	0.494153	0.490477	0.566356
Standard deviation	0.054755	0.01043	0.009057
Sample variance	0.002998	0.000109	$8.2*10^{-5}$
Excess	2.289132	-4.6903	-2.27709
Asymmetry	1.56335	-0.0545	0.628249
Interval	0.119943	0.021483	0.019367
Minimum	0.471858	0.479278	0.560004
Maximum	0.591802	0.500761	0.579371
Sum	2.051967	1.960993	2.272086
Check	4	4	4
Largest (1)	0.591802	0.500761	0.579371
Smallest (1)	0.471858	0.479278	0.560004
Reliability level (95%)	0.087127	0.016596	0.014411

Impact

In order to determine the influence and usefulness of the published scientific work, it is worth reminding that the inter-industry complex is an integration structure that unites economically interconnected branches of the production and (or) non-production spheres and characterizes the interaction of different industries and their elements, different stages of production and distribution of the product. In order to correctly interpret the received data and calculations, we first want to note that as a result of the analysis of economic data of inter-industry balances for 36 leading countries of the world, gross value added (GVA) is a significant indicator. Thus, in 2019 (calculated once every five years), the economies of the following countries had the largest specific weight of industrial GVA: China - 36.7%, Korea - 33.7%, Czech Republic - 30.8%, Russia - 27.2% and Mexico – 26.3%. According to this indicator - 22.6%, Ukraine took 33rd place among 36 countries of the world. The total amount of VAT of industry in 2019 increased from 9116851.4 million dollars. in 2014 to 13330371.0 million dollars. in 2019 or by 146.2%. From 2014 to 2019, the following countries had the highest growth rates of industrial GVA: Korea – 203.4%, China – 200.3%, Estonia – 156.2%, Sweden – 154.7% and Russia – 153, 0% According to this indicator - 97.6%, Ukraine took the 35th place among 36 countries and had a decrease.

Considering the purpose of this research, we will substantiate or refute the hypothesis regarding the feasibility of maintaining and improving the econometric modeling of economic security cross-industry complex of Ukraine. Probability predicting the economic security of intersectoral complexes is significant advantage in modern economy. Based on this model, using regression equations, predictive calculations of the economic security of intersectoral complexes for the period up to 2030 were carried out (Figure 3).The proposed method using econometric models makes it possible to evaluate the results of the development of economic security of intersectoral complexes and respond to negative performance indicators. In addition, it is necessary to carry out strategic planning; it should include an active industrial policy in various sectors of the economy.

The main requirement when choosing a forecasting method is its sufficient simplicity, combined with acceptable efficiency and reliability. The scientific literature on socio-economic forecasting, including sectoral forecasting, offers several hundred methods for developing forecasts.

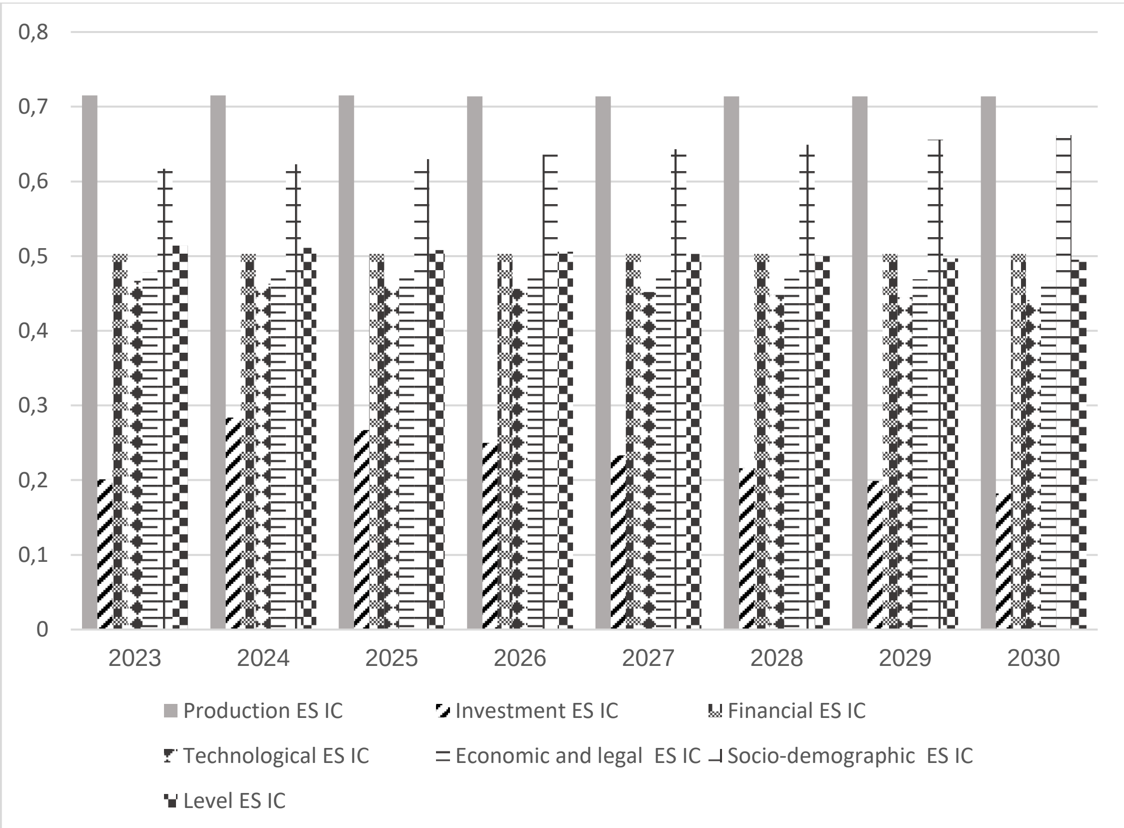

Figure 3. Econometric modeling of economic security of intersectoral complexes. *Source: Authors development.*

In this situation, it is impossible to give unambiguous advice on choosing the optimal forecasting method - one should be guided by the specific goals for which the forecast is carried out, consider the hierarchical level of forecasting, the characteristics of the available data on the socio-economic system, and much more. Quite often, the choice of a forecasting method is determined not by the appropriateness of its application, but by the information available to the researcher.

Forecasting methods are enriched and improved at an accelerated pace. Two factors play a special role in this. The first is the economic crises of the last quarter of the 20th century. They forced economists and managers to look for new adequate management methods. The second factor is related to the rapid spread of information technologies and computer equipment. These tools have made outlook analysis and forecasting publicly available. They made it possible to automate, simplify and speed up the execution of a huge number of planning and control functions.

The main requirements for this information base are:

- probability of quantitative characteristics of indicators;
- sufficiency and completeness of the provided information;
- the systematic nature of the provided information, which implies the possibility of interlinking the indicators of different information blocks and levels;
- comparability, i.e., consistency of quantitative characteristics of various indicators with each other.

The use of econometric modeling and forecasting of the economic security of the inter-industry complex can be justified by the following reasons:

- firstly, the mechanism of regulation of production, consumption, exchange and distribution in the economy is characterized by a complex of centralized and autonomous decisions, the consequences of which can only be described as stochastic processes. Econometric analysis is intended for modeling such processes. Only on its basis it is possible to establish which economic indicators have dependencies, what is the analytical nature of relations and relationships between economic phenomena and what are their numerical values;
- secondly, the use of scientifically based complex econometric models allows for meaningful analysis and forecasting of economic development. Econometric methods make it possible, in addition to the main variants of forecasts, to model many subsequent variants, in which, as a result of expected changes in economic policy, certain externally specified (exogenous) variables change. This use of econometric models allows to determine the consequences of a number of predictive options for development and at the same time ensures consistency and connection of the studied indicators;
- thirdly, econometric modeling and forecasting is a fairly effective tool for controlling the proportions of economic development. Complex econometric models reflect the structural and dynamic changes that are occurring as a whole. This allows you to check compliance with the main proportions of the most important indicators during the specified period and provides information for making decisions about the most appropriate measures of economic policy.

Conclusions

The use of econometric modeling and forecasting of the economic security of an interdisciplinary complex makes it possible to single out and formally describe the most important, most essential connections between economic variables and objects, as well as to obtain new knowledge about the object in an inductive way. In such modeling and forecasting, in a simplified form, under many assumptions, the main dependencies between economic indicators are established. Thus, econometric modeling and forecasting of the economic security of an interdisciplinary complex is not only a powerful tool for obtaining new knowledge in the economy, but also a very important component in justifying the adoption of practical management decisions. To improve the financial condition and ensure financial stability, it is necessary to apply econometric modeling and forecasting of the economic security of the inter-industry complex. The process of developing management decisions to ensure a sufficient level of economic security of the interdisciplinary complex must be scientifically based. This involves the use of econometric modeling and forecasting. In the circumstances that have developed in most branches of Ukraine at the moment, there is practically no potential for development due to the war and aggression of the Russian Federation. Leading enterprises are developing development programs that provide for the expansion of production capacities, renewal of production equipment, development of the scientific base, improvement of the consumer properties of the products produced, as well as those produced

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in future periods after the implementation of all works related to the return to the pre-war period. It should be recognized that this is the only possible way out of the crisis and transition to the development of industries. In this case, the approach proposed by the authors regarding the implementation of econometric modeling as a strategic lever for planning the development of the inter-industry complex is clearly followed. However, the implementation of these programs is complicated due to the lack of adequate funding at the moment, since most enterprises, if they do implement technological innovations, do so mainly at the expense of their own funds, which currently slows down the time for their implementation. Without pretending to be exhaustive of the systematic assessment of the economic security of enterprises, it should be concluded that the necessary conditions for the formation of an effective system of economic security of the inter-industry complex of Ukraine are as follows: increasing the level of security of entrepreneurship due to the strengthening of the responsibility of the state (legal, judicial, institutional, etc.) to economic entities activities; the effectiveness of the business support policy; implementation of adaptive security management systems; ensuring the internal balance of the main economic parameters of regional enterprises; strategic focus on long-term and rational development.

Conflict of interest

There are no conflicts to declare.

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