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Original Scientific Paper

NEW METHODOLOGY TO STUDY CONTAGION BETWEEN WESTERN AND EMERGING EUROPE: A SWITCHING COPULA APPROACH

UDC 336.7

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Abstract. *This paper adapts and extends switching copula models to investigate whether financial contagion occurred between Western stock markets and their Central and Eastern European counterparts during the Global Financial Crisis. Our methodology focuses on tail dependence as a direct measure of codependence in crisis times and we apply it to two bespoke indices that cover the biggest Central and Eastern European stock markets. We find an overall increase in dependence between Western Europe and the transition region during the Great Recession. However, adding the Turkish stock market to our CEE regional indices reduces the duration of the impact of the crisis. These results suggest that the transition economies remain a valuable diversification source during periods of crisis.*

Key words: *Contagion, International financial markets, Financial integration*

JEL Classification: C32, F36, G15

1. INTRODUCTION

In the two decades prior to 2008, the transition region of Central and Eastern Europe (CEE) saw a steady economic growth due to the financial integration with Western Europe (Friedrich et al. 2013; Haselmann et al. 2009). However, the sharp decline of the stock markets of these countries during the Global Recession following the Lehman Brothers' collapse raised the question whether in addition to their superior returns in economic

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upturns, they are a viable source of diversification in times of a turmoil. Therefore, the current paper investigates whether the financial markets in the CEE region became more interdependent with Western European (WE) markets during the crisis, which may cast doubt on the region's diversification potential.

We focus on the period from the beginning of 2007 to the beginning of 2010 and examine the stock markets of nine transition economies: Bulgaria, Croatia, Hungary, the Czech Republic, Estonia, Poland, Romania, Slovenia and Turkey, and one general Western European index, the Stoxx600. In our approach, we use an increase in the volatility in the Western European index as a potential trigger of financial contagion from WE to CEE.

Our methodology derives from the latest advancements in the literature on measuring financial contagion. In the last two decades, the discussion on contagion departed from the assumption of linearity, imposed by the definition of the Pearson correlation coefficient, and recognized the importance of tail events in gathering a finer grasp of the stock market fluctuations. This is intuitive, since a crisis is a tail event itself. Thus, extreme value theory and Markov switching models are becoming increasingly important in analyzing the phenomenon of contagion (see Longin & Solnik 2001; and Hartmann et al. 2004, for the former approach, and Ramchard & Susmel 1998; Ang & Bekaert 2002; and Rodriguez 2007, for the latter).

When we consider dependence, a natural concept that comes to mind is the copula, that is, the pure dependence structure between individual markets. Therefore, to gauge financial contagion, we apply switching mixture copula models that capture the influence of different variance regimes, following the approach of Rodriguez (2007). Using this methodology, Rodriguez (2007) manages to identify not only differences in the level (the magnitude of the copula parameters), but also in the structure (the specific proportion of each copula in the copula mixture) of dependence between periods of low and high volatility. The most important benefit of the copula approach is that it provides direct estimates of tail dependence, i.e., the probability that two markets are simultaneously in extreme good or bad states. This concept allows us to test our predictions with regard to the behaviour of stock markets during crisis episodes.

To exemplify the usefulness of our approach, we examine the dependence patterns between WE and the overall CEE region. To this end, we construct a Central and Eastern European Index (CEEI) as a weighted average of the stock market indices of the nine transition economies in our sample. This should help us to distinguish any asymmetric responses at the regional level.

Our results show the following: First, we generally confirm the existence of contagion of the type proposed by Forbes & Rigobon (2002) in a broad sense – the regional dependence does increase at the time of the peaks of the crisis in the Western markets. As far as the second hypothesis is concerned – whether markets tend to comove to a higher extent during downturns than during upturns, at the regional level, we witness a balanced dependence structure, with a fairly symmetric level of dependence in both tails.

We have several contributions to the existing financial contagion literature. First, we are among the few to apply copula theory to study the contagion between Central and Eastern Europe and Western Europe during the subprime crisis, with an explicit focus on tail dependence. Second, the use of Markov Chain models like SWARCH allows us to endogenize crisis periods, instead of setting arbitrarily fixed dates like previous studies. Third, we extend the switching copula methodology to allow us to make not only qualitative, but also quantitative statements about the form of dependence, and thus – to gain more intuition about the level of interdependence between WE and CEE markets during the subprime crisis.

This paper is organized as follows: Section 2 places the current work within the existing literature regarding contagion and the dependence between the financial markets of WE and CEE. In section 3, we introduce our switching copula methodology, outline its properties and provide guidelines on how our results should be interpreted. Section 4 discusses our dataset and empirical strategy, while section 5 presents our empirical results. Section 6 summarizes our results, and discusses possible policy implications and venues for further research.

2. LITERATURE REVIEW

The debate on the issue of contagion in stock markets gained momentum after the 'Peso' and Russian crises in the 90s. This notion is usually discussed in the context of the findings of Longin & Solnik (2001), who observe a rise in dependence in bear, but not in bull markets. Forbes & Rigobon (2002) define financial contagion as a substantial rise in market interlinkages after an adverse event in a particular market or region. While the early empirical evidence confirms the rise of correlation during stock market crashes (see Bertero & Mayer 1990; and King & Wadhwani 1990, for the 'Crash of 1987'), Boyer et al. (1999) and Forbes & Rigobon (2002) did not find structural breaks in correlation once they accounted for conditional heteroskedasticity.

In the early research activity with regard to the stock markets of the transition economies, authors usually prefer to use vector autoregressive models to detect any cointegration relationships between CEE and WE and do not explicitly concentrate on extreme-event comovement and contagion during crisis periods (see, e.g., Horváth & Petrovski 2012, Egert & Kočenda 2011; Tilfani et al. 2019; and Beck & Stanek 2019).

More recently, researchers have started to apply VAR methods to study contagion in CEE more generally and financial contagion in particular. Baruník & Vácha (2013) use wavelet theory to address some deficiencies in standard VAR methods applied to time series and find that contagion within the CEE region, measured by conditional correlation, has dropped during the Global financial crisis. Not focusing on any specific crisis period, Baele et al. (2015) document significant heterogeneity in stock markets development in the region since 1990 and that smaller and less liquid markets offer high diversification benefits. The authors also find significant premiums in investing in low-volatility markets. Horváth et al. (2018) apply VAR models and quantile regressions to measure financial contagion as defined by Forbes and Rigobon (2002) and find evidence that general dependence between WE and CEE stock markets increases during crises. However, using their methodology, they are not able to generate exact estimates of tail dependence and set the crisis period exogenously, in contrast to our Markov-Chains-based approach that defines crisis periods endogenously. Using DCC-GARCH model, Csiki & Kiss (2018) find evidence for increased correlation between Poland, Hungary and the Czech Republic with the USA and Germany. Moagăr-Poladian et al. (2019), Niţoi & Pochea (2019) and Grabowski (2019) find similar results using a GARCH-MIDAS approach.

Overall, these studies suffer from the shortcoming of the earlier literature: They focus on general linear correlation (albeit sometimes in the tails), rather than on tail dependence (which is a probability concept), do not assess how symmetric the market response is in good and bad times and in both tails of the distribution, and define the crisis periods exogenously.

To our knowledge, only a couple of recent studies, Reboredo et al. (2015) and Mohti et al. (2018), apply copulas to study financial contagion in the CEE region and are therefore the most closely related articles to our paper. Reboredo et al. (2015) use dynamic Student-t, Gaussian, Clayton and Gumbel copulas to find the best fit to the data and document that dependence among CEE markets increases during crises and that it is mostly symmetric within the geographic region. In contrast to that study, we focus on tail dependence between CEE *and WE* and find that the dependence is symmetric at the region-region level. Mohti et al. (2018) analyze financial contagion between the USA and a number of emerging markets in Asia, South America and CEE and find an increase in dependence during the Global financial crisis for CEE. These two studies suffer from the pitfalls of most other studies that apply copulas to study financial contagion: First, they horse-race a large number of copulas with different characteristics and properties and look for the one with the best fit with the data. This leads to interpreting the parameters of the 'winning' copula, which do not always represent tail dependence directly. Instead, in our case, we use a flexible mixture copula with parameters that exactly measure lower and upper tail dependence. Second, they set the crises periods exogenously and arbitrarily. Our SWARCH approach allows us to endogenously identify periods with high volatility in stock markets. Both these features of our approach yield superior modelling and intuitive interpretation of our results.

In a more general context, in terms of sophistication of the copula approach, our study shares common features with the approach of Johansson (2011) (aside from the obvious similarities with Rodriguez 2007 that we compared with in the introduction). Johansson (2011) models the asymmetry in the volatility of East Asian and WE stock markets using an EGARCH model and estimates the upper and lower tail dependence using a symmetrized Joe-Clayton (SJC) copula. The author documents increased volatility in the beginning of the crisis and the period around the bankruptcy of Lehman Brothers, but assigns the starting dates and the lengths of those periods exogenously, while we endogenize them. A second differentiation is that the copula function that Johansson (2011) uses is time-varying, which allows the author to capture the time path of the tail dependence, while we assume a constant dependence structure that may be different in each of the volatility states that we model. The implementation of a time-varying approach has it pitfalls, as the results are sensitive to the choice of lags and length of the rolling estimation window in the time-variation-forcing mechanism. Also, although the author documents shifts in tail dependence in Western Europe and Asia during periods of high volatility, he does not analyze different volatility regimes that might lead to a structural break in the tail dependence. Fourth, the author does not differentiate between lower and upper tail dependence, while this differentiation is crucial for the current analysis, since it allows us to analyze any potential asymmetric dependencies between the WE and CEE regions. Finally, while Johansson (2011) examines the within-regional tail dependence of the WE and Asian stock markets, we focus on cross-regional tail dependence, since our aim is to investigate contagion patterns between WE and CEE regions.

3. Methodology

Our procedure entails using publicly available data to model the marginal distributions of the investigated markets as a first step. We start by creating a Central and Eastern European Index (CEEI) to analyze the behavior of the region as a whole. Following Hamilton and Susmel (1994) and Rodriguez (2007), we use a Switching ARCH (SWARCH) model to describe the marginal behaviour of each stock market.

As a second step, we use the results from the SWARCH estimation to model the *joint* behaviour between the CEE countries and Western Europe using copula models. We extend the approach of Rodriguez (2007) by introducing a switching parameter version of a specific copula, the symmetrized Joe-Clayton copula, developed by Patton (2006). Using a single copula, we avoid the non-nestedness of the structures derived from general copula mixtures, which allows us to compare the results across different markets. The symmetrized Joe-Clayton copula is flexible enough to capture differences in both the *level* and the *structure* of dependence. Most importantly, this copula's parameters are consistent *tail dependence* estimates, that is, estimates of the probability of the markets to simultaneously be in extreme good or bad states.

3.1. Switching ARCH Model (Hamilton and Susmel 1994)

We estimate the characteristics of the marginal distributions of the time series using an AR(p)-SWARCH(K,q) model (Hamilton and Susmel 1994). To this end, we assume that the conditional mean follows a regime-dependent process:

$$y_t = \mu_{s_t} + \tilde{y}_t, \tag{1}$$

with μ_{s_t} being the mean in the states $s = 1, 2, ..., K$ at the respective time t. $\tilde{y}_t$ is governed by a zero-mean p^{th}-order autoregressive process,

$$\tilde{y}_t = \phi_1 \tilde{y}_{t-1} + \phi_2 \tilde{y}_{t-2} + \cdots + \phi_p \tilde{y}_{t-p} + u_t. \tag{2}$$

Furthermore, we model the error term as:

$$u_t = \sqrt{g_{s_t}} \cdot \tilde{u}_t, \tag{3}$$

with $\tilde{u}_t$ following an ARCH(q) process:

$$\tilde{u}_t = h_t \cdot \nu_t, \tag{4}$$

where ν_t is an i.i.d. sequence with a mean equal to zero and a variance equal to one. Also, h_t follows

$$h_t^2 = a_0 + a_1 \tilde{u}_{t-1}^2 + a_2 \tilde{u}_{t-2}^2 + \cdots + a_q \tilde{u}_{t-q}^2. \tag{5}$$

The changes in the regimes are captured via changes in the level of the variance process in each state (represented by g_{s_t}).

A Markov chain of the following form describes the latent variable:

$$P = \begin{bmatrix} p_{11} & p_{21} & \cdots & p_{k1} \\ p_{12} & p_{22} & \cdots & p_{k2} \\ \cdots & \cdots & \cdots & \cdots \\ p_{1k} & p_{2k} & \cdots & p_{kk} \end{bmatrix},$$

with $\mathrm{Prob}(s_t = j \mid s_{t-1} = i) = p_{ij}, i, j = 1,2, \dots, K$, and where the sum of every column is 1.

We choose to model the stock market returns using an AR(1)-SWARCH (2,1) model, which yields parsimonious results and secures convergence. The residuals ν_t are Student t-distributed.

3.2. Copulas and Tail Dependence

Using copula theory (Sklar 1954; Cherubini et al. 2004), we define tail dependence as

$$\tau^U = \lim_{q \to 1} Pr[U_1 > q \mid U_2 > q] = \lim_{q \to 1} \big(1 - 2q - C(q,q)\big)/(1 - q), \tag{10}$$

and

$$\tau^L = \lim_{q \to 0} Pr[U_1 < q \mid U_2 < q] = \lim_{q \to 0} C(q,q)/q, \tag{11}$$

with τ^U and τ^L being estimates of, respectively, upper and lower tail dependence. U_1 and U_2 are uniform integral transforms of processes X_t and Y_t, $U_1 = F_1(X_t)$ and $U_2 = F_2(Y_t)$, and $X_t = F_1^{-1}(U_1)$ and $Y_t = F_2^{-1}(U_2)$; q is the quantile of an univariate distribution and $C(q,q)$ is a bivariate copula (Sklar 1954).

The dependence structure can be estimated using many different copulas, which are then usually ranked with the Akaike Information Criterion (AIC) to find the best fit. This widely spread approach is problematic because of the non-nestedness of the different copula families. Therefore, the tail dependence estimates are not comparable across copulas. We solve this problem by using a flexible mixed copula, the symmetrized Joe-Clayton copula (SJC copula; Patton 2006). The SJC copula can capture any type of asymmetry in the tail dependence between markets, including the case of independence. Another valuable feature is that, in contrast to most other copulas, where a transformation of the copula parameters is needed to arrive at tail dependence estimate, the parameters of the SJC copula themselves are consistent estimates of τ^U and τ^L. Our innovation to the approach is that the parameters change with the state of volatility between markets.

The standard Joe-Clayton copula (JC copula; Patton 2006) takes the following form:

$$C_{JC}(u, v \mid \tau^U, \tau^L) = 1 - \left(1 - \{[1-(1-u)^\kappa]^{-\gamma} + [1-(1-v)^\kappa]^{-\gamma} - 1\}^{-1/\gamma}\right)^{1/\kappa}, \tag{12}$$

where $\kappa = 1/\log_2(2-\tau^U)$, and $\gamma = -1/\log_2(\tau^L)$.

The standard JC copula possesses intrinsic asymmetry even with equal upper and lower tail dependence, hence Patton (2006) introduces the SJC as:

$$\begin{aligned} C_{SJC}(u, v \mid \tau^U, \tau^L) = 0.5 \left(C_{JC}(u, v \mid \tau^U, \tau^L)\right) \\ +0.5\left(C_{JC}(1-u, 1-v \mid \tau^U, \tau^L) + u + v - 1\right), \end{aligned} \tag{13}$$

with $C_{JC}(1-u, 1-v \mid \tau^U, \tau^L) + u + v - 1$ being the *Survival* JC copula.

3.3. Switching Copulas

Next, we introduce the mechanism of work of the switching copula for the bivariate case. Following Ramchard and Susmel (1998) and Rodriguez (2007), we assume that one of the markets, the WE market, is the source of change in volatility and tail dependence. In a two-market setting, there are four states in the Markov Switching Model. As an example, the states of volatility for WE and Poland at time t are as follows:

$s_t = 1$: Poland – Low Variance; Western Europe – Low Variance.
$s_t = 2$: Poland – High Variance; Western Europe – Low Variance.
$s_t = 3$: Poland – Low Variance; Western Europe – High Variance.
$s_t = 4$: Poland – High Variance; Western Europe. – High Variance.

The elements of the transition matrix P are of the following form: Pro b$(s_t = j \mid s_{t-1} = i) = p_{ij}$. According to Hamilton and Gang (1996), due to its flexibility, such structure can accommodate different relationships between the univariate variance states. In case that, for instance, there is independence between Poland and WE, each bivariate transitional probability, for instance p_{24}, could be constructed as the product of the respective univariate probabilities. That is, $p_{24} = p_{12}^{WE} \cdot p_{22}^{PL}$.

Previous research has shown that the Great recession affected CEE markets through their links with WE (see, for instance, Dabrowski 2009 and Gardo and Martin 2010). Therefore, we set the copula parameters to change only when there is a switch from low to high volatility *in the WE market*. Hence, tail dependence in states 1 and 2, and in states 3 and 4, respectively.

Rodriguez (2007) explains that all parameters in the switching model, including these of the SJC copula change jointly when there is a switch in the states of volatility. Therefore, we cannot separate the estimation of the marginal distribution and the copula in two steps, as usually done in previous research.

The likelihood function then takes the following form:

$$q_t(x_t, y_t \mid I_{t-1}; \Theta) = \sum_{s_t} \sum_{s_{t-1}} f_t(x_t \mid s_t, s_{t-1}, I_{t-1}; \Theta) \times g_t(y_t \mid s_t, s_{t-1}, I_{t-1}; \Theta) \times c^{SJC}(u_t, v_t \mid s_t, s_{t-1}, I_{t-1}; \Theta) \times P(s_t, s_{t-1} \mid I_{t-1}; \Theta), \quad (14)$$

with $P(s_t, s_{t-1} \mid I_{t-1}; \Theta)$ being the probability of each state at time *t* given the information set up to *t-1*; c^{SJC}, f and g are, respectively, the *densities* of the copula and the marginals. Θ represents the set of parameters, and $u_t = F_x(x_t \mid s_t, s_{t-1}, I_{t-1}; \Theta)$ and $v_t = F_y(y_t \mid s_t, s_{t-1}, I_{t-1}; \Theta)$ are the univariate conditional cumulative distribution functions. Then, the maximum likelihood function is represented by the following expression:

$$L(\Theta) = \sum_{t=1}^{T} lo\,g[q(x_t, y_t \mid I_{t-1}, \Theta)] \quad (15)$$

In our exposition, we prefer to report the *smoothed* probabilities $P(s_t \mid I_T; \Theta)$, instead of the *filter probability* $P(s_t, s_{t-1} \mid I_{t-1}; \Theta)$. The smoothed probabilities take into account the information set of the complete sample. For the univariate series, there are two probabilities – for low and high volatility state, respectively, and for the bivariate case, we arrive at four series for the smoothed probabilities.

4. DATA

4.1. Country and Regional Data

Our dataset consists of ten stock price indices, downloaded from Datastream. The sample period extends from 03.01.2007 to 09.02.2010. We consider 9 CEE markets, which, ordered alphabetically, are: Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Poland, Romania, Slovenia and Turkey. The dynamics of WE markets is proxied by Stoxx600. Every data series consists of 810 observations at a daily frequency.

To arrive at tail dependence at the regional level, we introduce 2 variants of our CEE index (CEEI): CEEI includes the member countries of the European Union at the time of the Great Recession, while CEEI2 adds Croatia and Turkey.

4.2. Descriptive Statistics

In Table 1, we show the market capitalizations of the CEE countries in our analysis, as well as the weights of each market in the respective CEEI indices. The captured regional market size increases from €260 Billion in CEEI, to €405 Billion in CEEI2. In Table 2, we show additional distributional descriptive statistics of the daily logarithmic returns of both indices. For both indices, we observe average returns below zero, left skewness, and, overall, the normality of the series is rejected (see the Jarque-Bera test statistic). These observations confirm the fat tails of both series and provide support for our choice to use Student t-distribution for the SWARCH model.

Table 1 summarizes the market capitalizations (row "M. Cap.", in millions of Euro) of the stock markets of the CEE countries in our sample in the end of 2006. Also listed are the weights of each country in the respective CEEI and CEEI2 index (rows "Weights CEEI" and "Weights CEEI2").

Table 1 Central and Eastern European Indices: market capitalizations and weights

Country	Bulgaria	Czech Republic	Estonia	Hungary	Poland	Romania
Market Cap	14802	57835	9797	31689	112831	21527
Weights CEEI	0.0569	0.2224	0.0377	0.1219	0.4340	0.0828
Weights CEEI2	0.0365	0.1427	0.0242	0.0782	0.2785	0.0531
Country	Slovenia	Croatia	Turkey	TOTAL:		
Market Cap	11514	22006	123163	M. Cap.		Weights
Weights CEEI	0.0443			259994.3423		1.0000
Weights CEEI2	0.0284	0.0543	0.3040	405163.8072		1.0000

Table 2 presents descriptive statistics for the CEEI indices. CEEI includes Bulgaria, Czech Republic, Estonia, Hungary, Poland, Romania and Slovenia. CEEI2 adds Croatia and Turkey. Time period: 03.01.2007 to 09.02.2010.

Table 2 Descriptive statistics: Central and Eastern European Indices

Index	CEEI	CEEI2
Mean	-0.0451	-0.0162
St. Dev.	1.5304	1.5667
Min	-9.3839	-8.9880
Max	7.3266	8.7151
Skewness	-0.4016	-0.2666
Kurtosis	4.7169	4.1675
Jarque-Bera	771.7342	595.0321
Observations	809	809

5. EMPIRICAL RESULTS

5.1. Univariate Results

In Table 3, we present the results for the marginals estimation for CEEI and CEEI2. Both series have a positive autoregressive component. However, only CEEI has significant ARCH effects. The parameter *g*, which represents the average difference in volatility between the two states is the same for both series, at 5.19 times.

Table 3 presents the univariate results from running a switching ARCH model on the log-returns of our index series. We use a model with one lag for the autoregressive part and ARCH parts and two volatility states (hence, we use a AR(1)-SWARCH(2,1) model). Time period: 03.01.2007 to 09.02.2010. Indices: as shown in the table. Standard errors in parentheses. Statistical significance at the 1, 5 and 10 percent levels is denoted by ***, **, and *, respectively.

Table 3 Univariate index results, SWARCH model

Markets	CEEI	CEEI2
C	0.0130	0.0554
	(0.0378)	(0.0430)
AR(1)	0.1218***	0.0828**
	(0.0379)	(0.0376)
K	0.7230***	1.0706***
	(0.1287)	(0.1692)
ARCH(1)	0.0796*	0.0229
	(0.0435)	(0.0467)
g	5.1893***	5.1852***
	(0.8192)	(0.8699)
DoF	7.5722***	10.0821***
	(2.3573)	(3.5362)
Log Lik	1346.5766	1393.2723

In Figure 1, we show the results for the smoothed probabilities of the high-volatility state for the markets in our sample for our CEEI indices. We observe that WE is in the high volatility state for a shorter period of time than CEE during the peaks of the financial crisis, especially around the collapse of Lehman brothers in September 2008. Adding Turkey in CEEI2 reduces the volatility of the index, most notably in the period after May 2009. This figure shows unequivocally that CEE markets enter periods of instability in response to increases in uncertainty on WE markets.

Figure 1 presents the smoothed probabilities that the stock index in question (Stoxx600, CEEI or CEEI2) is in high volatility state (this probability is denoted by "Pr. H State"). For interpretation of the figure, see Figure 1 or the text. Stoxx600 is included for the sake of comparison. Time period: 03.01.2007 to 09.02.2010. Indices: as shown in the figure.

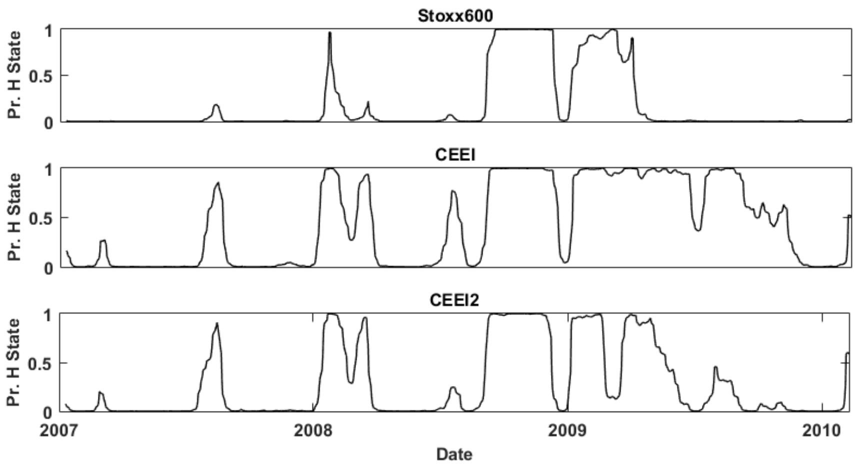

Fig. 1 Univariate case: smoothed probabilities, high volatility state

5.2. Bivariate Results

Figures 2 and 3 present the bivariate smoothed probabilities. The top subplot depicts the probability that both markets are jointly in a state of low volatility. In the second subplot, the WE market is in the calm state and the respective CEE index is in a state of high volatility. The lower two subplots present he cases where WE is in turmoil and CEE is in the calm and highly volatile state, respectively. We observe that in both figures, in State 4, the dynamics matches the results for the univariate smoothed probabilities of WE in Figure 1. This means that when WE is in a turmoil, both versions of the CEE index are in a state of high volatility, once again supporting our assumption that a crisis in WE markets starts before a crisis on CEE markets.

Supporting the last point, on both graphs, we notice a small peak around Lehman Brothers' bankruptcy in September 2008 for State 3. This indicates that WE enters the high volatility state first, and a few days later it is joined by the transition region (evident by the huge and prolonged peak in State 4 where both markets are in high volatility state). Even if this is not a direct proof that the crisis in the latter region was caused by the turmoil in the Western markets, we at least find evidence that the crisis in CEE was preceded by the crisis in WE (hence suggesting Granger causality).

Figure 2 presents the smoothed probabilities that the bivariate couple Stoxx600 – CEEI is in any of the four states described in Section 4.3. The top subplot depicts the probability that both markets are jointly in a state of low volatility. In the second subplot, the WE market is in the calm state and the respective CEE index is in a state of high volatility. The lower two subplots present the cases where WE is in turmoil and CEE is in the calm and highly volatile state, respectively. We assume that the dependence structure changes only when WE shifts from low to high volatility state (for example, from states 1 or 2 to states 3 or 4; see Section3.3.). Time period: 03.01.2007 to 09.02.2010.

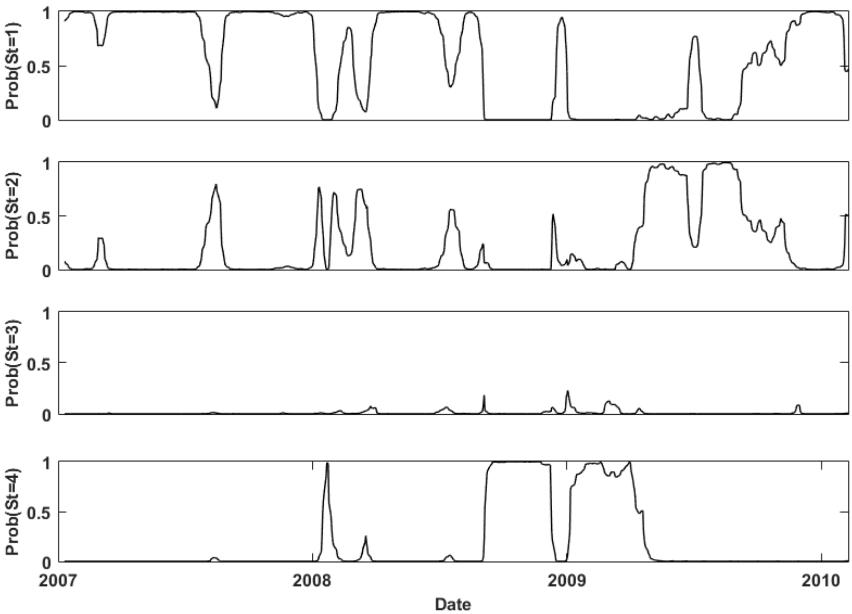

Fig. 2 Bivariate case: WE – CEEI

Comparing Figures 2 and 3, we notice that the probability of both WE and CEE regions to be in low volatility state (State 1) is much higher for CEEI2 than for CEEI after the first quarter of 2009. As Turkey is the bigger of both countries added in the broader index, our results suggest that through its diversified economy, this country improves the stability and resilience of the region to external shocks.

Figure 3 presents the smoothed probabilities that the bivariate couple Stoxx600 – CEEI2 is in any of the four states described in Section 4.3. The top subplot depicts the probability that both markets are jointly in a state of low volatility. In the second subplot, the WE market is in the calm state and the respective CEE index is in a state of high volatility. The lower two subplots present the cases where WE is in turmoil and CEE is in the calm and highly volatile state, respectively. We assume that the dependence structure changes only when WE shifts from low to high volatility state (for example, from states 1 or 2 to states 3 or 4; see Section 3.3.). Time period: 03.01.2007 to 09.02.2010.

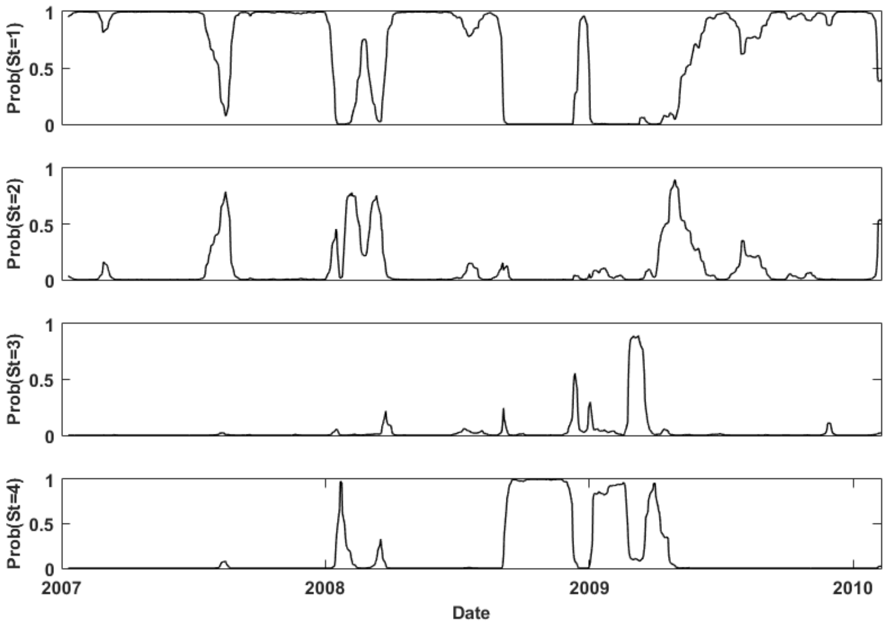

Fig. 3 Bivariate case: WE – CEEI2

Turning to the analysis of tail dependence between WE and CEE. The main hypothesis that we test is whether tail dependence increases during turmoils. To this end, we turn our attention to the tail dependence estimates as represented by the coefficients of the switching copula. Table 4 summarizes our estimates of upper and lower tail dependence, τ^U and τ^L. We notice that all tail dependence coefficients are statistically significant at the 1% level. When we compare upper and lower tail dependence in low and high volatility states, we observe that the dependence structure becomes more symmetric in crisis times (that is, during high volatility periods). The asymmetry in tranquil times is more noticeable for the wider index, where we witness lower upper and higher lower tail dependence, compared to the respective estimates for CEEI. We also notice that for both indices the lower tail dependence increases substantially in high volatility times (37.5 and 24.6 percent for CEEI and CEEI2, respectively).

Table 4 presents the tail dependence estimates of a switching symmetrized Joe-Clayton (SJC) copula between Western Europe (WE) and the two CEEI indices, as well as their relative change (in %) when WE is in low and high volatility states, respectively. The bottom two rows present the ratios between lower and upper tail dependence in the low and high volatility states. Time period: 03.01.2007 to 09.02.2010. Indices: as shown in the table. Standard errors for the individual tail dependence coefficients in parentheses. Statistical significance at the 1, 5 and 10 percent levels is denoted by ***, **, and *, respectively.

Table 4 Tail dependence results: CEEI and CEEI2

Markets	CEEI	CEEI2
τ^U(WE low)	0.4023***	0.3784***
	(0.0593)	(0.0675)
τ^U(WE high)	0.6307***	0.6503***
	(0.0284)	(0.0266)
τ^L(WE low)	0.4892***	0.5436***
	(0.0447)	(0.0415)
τ^L(WE high)	0.6724***	0.6773***
	(0.0228)	(0.0235)
Log Lik	3872.1934	3889.3090

These results suggest that a shift in dependence between CEE and WE did occur when Western markets entered high volatility states. However, although we observe an *asymmetric* dependence structure between the regions when WE markets are in low-volatility state, we do not confirm its existence during high-volatility periods. Nevertheless, lower tail dependence does increase during a turmoil, confirming our expectations. The overall dependence between the regions is relatively symmetric in such periods, but at a higher level. Hence, we find support for the existence of financial contagion (as defined by Forbes & Rigobon 2002) at the *regional* level.

6. Conclusion

We introduce an innovative approach to analyze the interactions between the financial markets of WE and CEE during the Great Recession. This new approach allows us to investigate changes in both the level and the symmetry of interdependence.

Our results suggest that dependence, in particular lower tail dependence, has increased during the peaks of the global financial crisis. In general, the two CEE indices that we introduce follow the dynamics of their bigger constituents, Poland and Turkey, and the inclusion of the latter country reduces the duration of the crisis periods in the region. Surprisingly, we find that the tail dependence on the WE region – CEE region level is symmetric during periods of high volatility. However, the level of tail dependence (both upper and lower) of around 0.60 in high volatility states seems exceptionally high and further analysis at the country level is warranted to reveal the interactions between individual markets and the WE and whether there is evidence for heterogeneity within the region.

The outcomes of our study have important implications also for the ongoing economic and political integration within the EU and especially of Turkey with the EU. We find evidence that EU candidate countries could reduce the uncertainty and hence the vulnerability of CEE stock markets. This could be an important topic for further research.

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NOVA METODOLOGIJA ZA PROUČAVANJE TRANSMISIJE IZMEĐU ZAPADNE I SREDNJEISTOČNE EVROPE: PROMENLJIVE VEZE

Ovaj rad prihvata i proširuje modele promenljivih veza kako bi istražio da li se dogodila finansijska transmisija između zapadnih berzi i njihovih parnjaka u Centralnoj i Istočnoj Evropi tokom Globalne finansijske krize. Naša metodologija se fokusira na krajnju zavisnost kao direktnu meru ko-zavisnosti u vremenu krize i primenjujemo je na dva indeksa po meri koja pokrivaju najveće centralno- i istočnoevropske berze. Nalazimo uopšteno povećanje u zavisnosti između Zapadne Evrope i tranzicione regije za vreme Velike recesije. Međutim, dodavanje turske berze u naše CEE regionalne indekse smanjuje trajanje usticaja krize. Ovi rezultati sugerišu da tranzicione ekonomije ostaju vredni izvori diverzifikacije u kriznm periodima.

Ključne reči: *Transmisija, Međunarodna finansijska tržišta, Finansijska integracija*

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Review Paper

INTERNAL REPORTING ON PROCESS OPTIMIZATION MEASURES: COMBINATION OF ECONOMIC AND ENVIRONMENTAL ASPECTS

UDC 657.6

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Abstract. *Optimizing the cost situation is part of everyday business in a company. The research field of controlling has developed many instruments and methods for calculating potential savings and communicating them to the decision-makers. In the future, in order for companies to operate more sustainably it is necessary to weigh up optimization measures from an economic and environmental point of view. This paper proposes to supplement controlling reports with a matrix opposing economic and environmental impacts by individual optimization measures. This reporting method should assist decision-makers in the selection of optimization measures, taking into account economic and environmental aspects. LCA and LCC based evaluation of a biotechnological process step for glycoside production served as a case study. An example for impact presentation of switching to a sustainable electricity mix is shown.*

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JEL Classification: D24, L65, Q51

1. INTRODUCTION

The controlling department supports the management and prepares decision-making basis for the improvement of the company. One focus is on the optimization of costs. Potential cost savings are identified and strategies for implementation are proposed. This also includes the optimization of processes in order to raise cost saving potentials. In the last two decades, and in view of global warming, there has been an increasing focus on environmental concerns and the reduction of pollutant emissions (Keoleian & Menerey 2012; Anastas & Eghbali 2010). These aspects need reflection in parallel to cost aspects in environmentally conscious manufacturing and future decision-making support by controlling departments.

Life cycle costing (LCC) is an instrument with which the total costs of a product can be recorded, evaluated and optimised over its entire life cycle. This makes it possible to identify potential cost savings even before a product is launched on the market and while it is still in the product development phase. On the other hand, there is the instrument of environmental life cycle assessment (LCA), which enables a systematic analysis of the environmental impacts of products throughout their entire life cycle. The greatest opportunity for reducing the environmental impact of a new product in intervening in the life cycle of a product as early as the design phase (Fitzgerald et al., 2005).

The practical problem that arises here is that economic and environmental optimization are usually regarded as conflicting objectives of a company (e.g. Söllner 1998). In order to avoid one-sided cost optimization at the expense of the environment, essential agreements on climate protection have already been reached, among others, with the regulations of the Kyoto Protocol and then the successor agreement, the Paris Agreement. These agreements emphasize that companies from industrialized countries in particular must make their contribution to achieving the climate goals. As stated by Dascalu, Caraiani & Lungu (2008), the design of environmental policy thus has an influence on the costs of companies for climate protection. Increased efforts in implementing environmental protection measures elevate the need for evaluation of possible process optimizations from economic and environmental perspective. Often efforts in environmental protection are expected to rise costs. However, process optimization measures taken based on environmental assessment results can as well lead to cost reductions, a fact which might not be anchored well in managers' mindsets yet.

The research question for this paper is derived from this conflicting situation: How can suggestions for improvement be presented to management so that they can make a decision to implement them taking into account both the economic and environmental situation? We here demonstrate an easy-to-understand communication method for effects of suggested improvements taking into account results from LCC and LCA.

The method is showcased on first results from LCC and LCA evaluation of optimization of a biotechnological process for glycoside production. The process optimization and evaluation was done in the framework of the EU H2020 financed CARBAFIN project.

This paper consists of five sections, with this section being the first. The second section reviews literature described approaches taken to combine life cycle costing (LCC) and life cycle assessment (LCA). The third section presents the research methodology of this study including the approach to economic and environmental analysis. Combined LCC and LCA result presentation is shown for an application example in the fourth section. The fifth section contains the conclusion with the main results, limitations of this study and suggestions for further research.

2. Approaches for LCA and LCC Combination

In LCA the environmental impact of products or processes over their life cycle is evaluated. LCA methodology is described in standards ISO 14040:2006 and ISO 14044:2006 and together with LCC and sLCA as part of the UNEP/SETAC approach towards a life cycle sustainability assessment (Valdivia et al. 2013). LCA is now widely applied in many sectors (e.g. De Soete et al. 2017; Obrecht et al. 2020; Moretti et. al. 2021; Kumar & Verma 2021). Many approaches to LCAs have been established, as Fazeni, Lindorfer & Prammer (2014) describe in their paper. However, they explicitly emphasize that the connection to LCC is only very sporadic and that there is a need for further research to combine these approaches, which is still valid today. For example, Ouattara et al. (2012) propose in their paper combined mathematical, economic, and environmental optimization strategies for process design. However, this method might be considered as too complex for everyday application in controlling reports.

Approaches to optimizing technical, environmental and economic aspects have already been described for individual areas. Ribeiro et al. (2008) use a methodology to compare a set of candidate materials and identify the "best material domains" by aggregating the three dimensions (technical, economic and environmental). These "best material domains" are presented in a diagram. This enables a global comparison of candidate materials to support a decision on the selection of the best material according to different business scenarios and corporate strategies. The focus of their work is on the selection of the best materials, taking into account these three dimensions.

More recent literature shows that in some cases optimization is one-sided with a focus on cost optimization and that a more comprehensive optimization of all areas is required (e.g. Patel, Zhang & Kumar 2015). Current literature demonstrates that a comprehensive approach to process optimization from a technical, environmental and economic perspective is attracting more and more attention (Vaskan, Pachon & Gnansounou 2017; Cavaignac, Ferreira & Guardani 2021). Ögmundarson et al. (2020) propose a framework for the optimisation of biochemical processes, which includes the environmental and economic components in the evaluation. Their framework uses a set of quantitative indicators from LCA and techno-economic assessment (TEA). As a result of the preceding LCA analyses, the total sustainability costs per given functional unit are calculated. This value reflects the human health costs, ecosystem quality costs and natural resources costs and can finally be combined with the techno-economic costs to a single monetary output value. This single output value for a combined LCA and LCC analysis contributes to the above mentioned easy-to-understand communication. However, the authors acknowledge the challenges related to subjective value choices in the monetization of human and environmental health which involve moral questions. For a broad overview on integrating life cycle assessment and life cycle cost we refer to Franca et al. (2021).

Pesonen & Horn (2013) name two main issues in the context of LCA from a management perspective that require further work: (1) approaches to speed up the resource-intensive inventory and assessment process, and (2) easy-to-understand communication of the results. In their study, they aim to contribute to these needs for faster and cost-effective ways to develop strategies that incorporate the life cycle perspective. Luthin, Backes & Traverso (2021) also address the combined assessment of LCC and LCA in a recent study developed at the same time and simultaneously to this paper. Visual solutions for comparison of LCA and LCC results for complete production scenarios for aluminum in three different countries were presented.

3. Methodology and Research Question

The main purpose of this paper is suggesting a communication method for expected effects of process improvement proposals, taking into account economic and environmental aspects. The focus is on internal reporting to the management in order to assist a well-founded decision on process improvements to be carried out. We focus on a suggestion for reporting of single improvement proposals taking into account results from prospective LCC and LCA. Since this is an optimization taking into account two dimensions, the bundle of individual measures can be represented in a diagram as a portfolio (matrix) with two axes. The portfolio theory has long been known (Markowitz 1952) and has already been applied in many business management issues (e.g. Baum, Coenenberg & Günther 2006). The application of such matrices has already been taken up in the literature, but mostly in connection with specific business areas (e.g. Simoes et al 2016). As a general basis for process improvement proposals, a 4-quadrant model is here suggested that shows economic and environmental implications for the implementation of improvement measures and can be integrated into controlling reports. While costs anyway are represented by a single monetary value, we use the sustainable process index (SPI) as aggregated single output value for environmental burdens. Further details are given below. The proposed reporting method serves as a guide for strategy recommendations, as it clearly shows which proposed measures are associated with savings in both economic and environmental terms, which have negative impacts in both categories, and which lead to a trade-off between environmental and economic aspects and therefore require special consideration. On the basis of a technical improvement proposal catalogue, the effects on the economic and environmental side can thus be easily examined.

3.1. Case study: Biocatalytic process for glycoside production

The here suggested combined LCA and LCC result presentation is show-cased on a unit operation "biocatalytic synthesis of a glycoside" of an existing biotechnological process. This approach emphasizes the value of the suggested method for controlling reports based on realistic numbers on the effect of electricity supply switch. While not relevant for showcasing the suggested presentation method, for completeness a short description of the process is given here. The economic and environmental process evaluation is a first partial result of the research project CARBAFIN, which is funded by the European Union H2020 program. CARBAFIN develops biocatalytic processes for the production of glycosides. Glycosides are chemicals that contain at least one sugar moiety attached by a glycosidic bond to a core molecule. A model product is 2-glucosylglycerol which finds application as moisturizer in cosmetic industries. Main raw materials for the biocatalytic synthesis are sucrose and glycerol. With the help of the biocatalyst the glucose subunit from sucrose is transferred to glycerol. Fructose is a side product. The project aims to evaluate implementation on an industrial scale. The approach in this multidisciplinary research project is designed in the sense of a single-case study (Yin 2011; Yin 2017) with the inclusion of several methods. The processes are optimized technologically as well as from an economic and environmental point of view. A full fletched combined LCA and LCC study on the CARBAFIN processes is intended to be published later.

3.2. Economic approach to process optimization

The procedure for creating a life cycle model was based on the standard literature on life cycle costing (e.g. Coenenberg et al. 2016; Ewert & Wagenhofer 2014). First of all, a distinction is made between the data gathering phase and the data processing phase. The evaluation of the case study process was done in a cradle to gate setting. Based on the process steps specified by the company, all cost types were first identified with the quantity inputs. In addition, the prices per unit of measure were collected. The data collection represented an elaborate process. First, the rough data was collected with the help of a questionnaire sent to the company. Missing data and inconsistencies were clarified and followed up in telephone calls and internet research.

In parallel, a life cycle cost model (e.g. Zehbold 1996) was developed in Microsoft Excel. A life cycle of 10 years was defined in consultation with the cooperation partner. The reason for the chosen timeframe is that after this period of time the plants have to be replaced. The collected data was then incorporated into the model. Operational expenditures were planned in detail for the first year. Since the annual production volume is assumed to remain constant for the life cycle, there is only an inflation due to inflation adjustments, which was considered separately for each cost type. In the case of capital expenditures, replacement investments were planned for individual parts of the production plant.

The model data can be used to determine various information for optimization proposals. Hotspot analysis is used to reveal the process steps that are expensive in the process. Furthermore, those cost types were identified which account for the highest proportionate costs over the entire process. This information is used to make suggestions for optimizing the use of raw materials and the process itself. For each feasible optimization measure, the costs before optimization were compared with the costs after optimization to determine a percentage cost difference on the total costs per step or process.

3.3. Environmental approach to process optimization

LCA is now a widely used methodology for the environmental sustainability evaluation for a product, process or service. LCA is an analytical tool to provide solid, comprehensive and quantifiable information about the environmental performance of products, processes or human activity throughout its entire life cycle (Audsley et al. 1997). The methodology is standardized by the International Standardisation Organisation (ISO) in the 14040 and 14044 series of ISO standards (ISO 2006) providing a general framework for conducting a life cycle assessment. An LCA is subdivided in four main phases as presented in Figure 1. Goal and scope definition; Life Cycle Inventory Analysis; Life Cycle Impact Assessment; and Life Cycle Interpretation. Results will depend on the selected evaluation methodology, data quality as well as the defined system boundaries. Although no environmental evaluation is telling the “ultimate truth”, LCA can point out relevant environmental aspects and is regarded a useful tool for decision making.

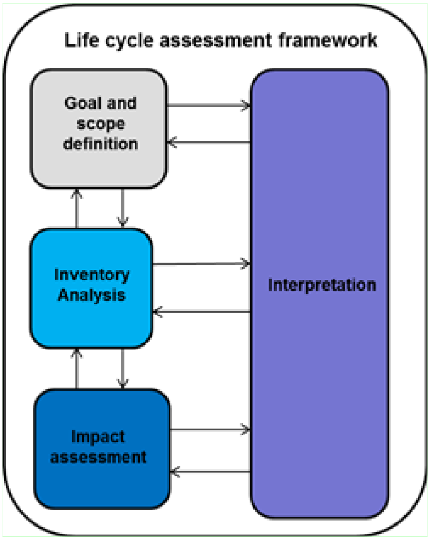

Fig. 1 Performing LCA is standardized
Source: ISO- Norm 14040 and 14044

In short, for the case study process the main phases were handled as follows:

Goal and scope definition

The goal of the study was internal evaluation of process options and development in the project. The case study evaluation was performed on a biotechnical process as implemented in a German manufacturing plant. The here shown example of change in electricity from conventional mix to a sustainable mix is only one first obvious option for improvement, in later project phases more options will be identified. The LCA was done in a cradle to gate manner. Functional unit was the yearly mass of glycoside product which is sold to B2B customers.

Life Cycle Inventory (LCI)

Inventory analysis included primary data from the manufacturer as well as secondary data for raw materials and energy provision (Ecoinvent database). Energy demand in the plant was partly calculated based on physical equations. The inventory items used are identical to the ones used for LCC except that no impact by personnel is taken into account while LCC data includes wages. The below shown results refer to the inventory of one single process unit operation, the biocatalytic synthesis step (fermentation of the biocatalyst is not included in this step).

Life Cycle Impact Assessment methodology – Sustainable process index (SPI)

As LCIA methodology the sustainable process index (SPI) method was used. The SPI calculates the environmental footprint as the cumulative area which is necessary to implant the entire life cycle of an industrial process, product or service in the biosphere in a strongly sustainable way. The SPI takes into account all relevant environmental impacts including all resulting emissions for the upstream chain to the end of life. Material and energy flows that are taken from and released to the ecosphere are compared with the natural flows (Narodoslawsky & Krotscheck 1995; Narodoslawsky & Stoeglehner 2010; Shahzad et al.

2014). The total area A_{tot} for embedding of human activities sustainably into the ecosphere is calculated. Areas comprising the overall footprint are shown in detail in Figure 2.

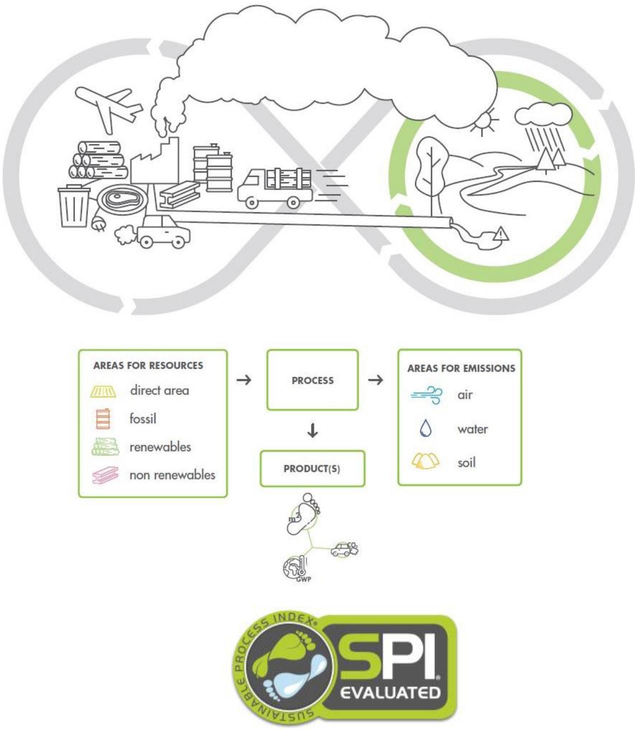

Fig. 2 Anthropogenic- vs. natural lifecycles - SPI calculation, material and energy flows of a process. "The more humans exceed these natural renewal rates, the larger the environmental footprint."
Source: adapted from SPIonWeb, ©STRATECO OG (SPIonWeb 2013-2019; STRATECO 2021)

The SPI method is available for application free of charge by the SPIonWeb software tool and methodology is described there in detail as well (http://spionweb.tugraz.at/ and https://spionweb.tugraz.at/en/spi). With this tool product life cycles are described as process chains that can be updated and further developed. As results the user gets the SPI footprint of a product or process as cumulated square meter number. CO_2 life cycle emissions and GWP of the whole life cycle (Neugebauer et al. 2015) can be calculated as well but were not used in this study. In comparison to other LCIA methods which evaluate environmental impacts in several more impact categories, the SPI delivers with the cumulative area of the footprint a single aggregated impact value which allows graphical representation together with costs in a single two-dimensional plot.

Interpretation

For interpretation of the results a visualisation in combination with LCC results is used in order to guide decision on whether to implement a suggested process change or not. While in the here presented case of electricity supply change the result is clear, in other cases changes in and trade-offs between environmental and economic impact will be more subtle. A sensitivity analysis of single parameters and a careful quality assessment of used data then is essential.

4. Results

In order to be able to communicate the effects of individual improvement measures to management, the economic and environmental impact reduction potentials or increases are presented in a matrix as a percentage of the total costs or the total footprint before the improvement. When the entire bundle of measures is presented, the result is a portfolio of measures that provides the decision maker with information on which measures have which economic and environmental impacts.

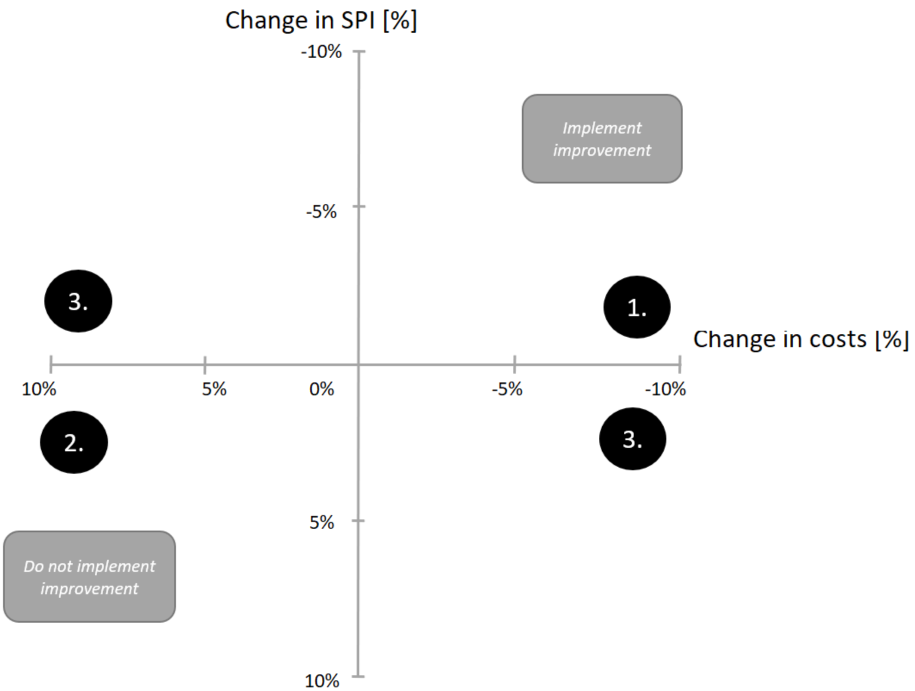

Fig. 3 Optimization matrix with implications for the implementation of process improvements

Figure 3 shows a matrix with the implications for implementing improvement suggestions. The origin with 0% describes the original costs and emissions before any process improvement. In the following, improvement measures are analyzed. These can be technical process improvements or changes in raw material or energy supply that have an impact on costs and the environmental footprint. In an iterative process, the feasibility is checked and the impact on the costs and the footprint is presented. The processes shown in the diagram are schematic. Cost or environmental footprint can increase or decrease compared to the reference process.

The individual potential process improvements are entered in the chart. Four directions emerge: Costs can rise or fall and emissions can rise or fall. There are therefore two clear implications. The improvement proposal should be implemented in any case if costs and emissions can be reduced (Implication 1). The measure should not be implemented if costs and emissions increase (Implication 2). The quadrants top left and bottom right represent a need for discussion within the company and must be decided on a situational basis (Implication 3). Often, the suggestions for improvement will be located in the upper left quadrant, when measures to improve the environmental footprint lead to an increase in costs (e.g. switching from petro-based packaging materials to sustainable degradable materials).

Case Study (biotechnological glycoside production)

The LCC and LCA was performed for a biotechnological glycoside production process of a cooperating company partner. The life cycle cost model was developed in an iterative process, with repeated consultations with the cooperation company on ongoing minor process changes, resource requirements and resource evaluation.

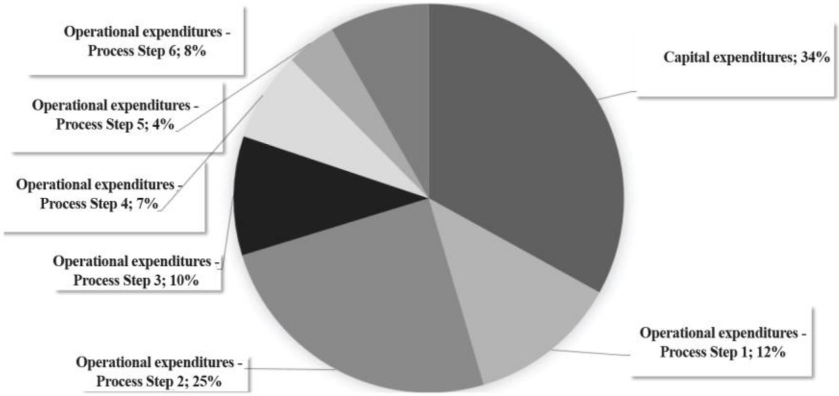

Fig. 4 Economic process hotspot analyses showcased for LCC analysis of a biotechnological glycoside production process

After modeling the data, they were evaluated. For this purpose, the operating expenses of all years were discounted to t=0 with the cost of equity of the company. The self-financed capital expenditures were also evaluated. No aftercare costs are incurred in the company at the end of the product life cycle, as the product does not incur disposal costs. The costs for dismantling as well as disposal of the plant are negligible in the company. On the basis of this information, it was possible to obtain an initial overview (Figure 4) of where the highest expenses are to be expected, so that suggestions for process improvement can be made. LCA was as well conducted based on the same boundaries and inventory as used for LCC analysis. Within the process step with highest costs and environmental footprint impacts of single inventory items are presented as percentage share of total cost or environmental footprint (Figure 5).

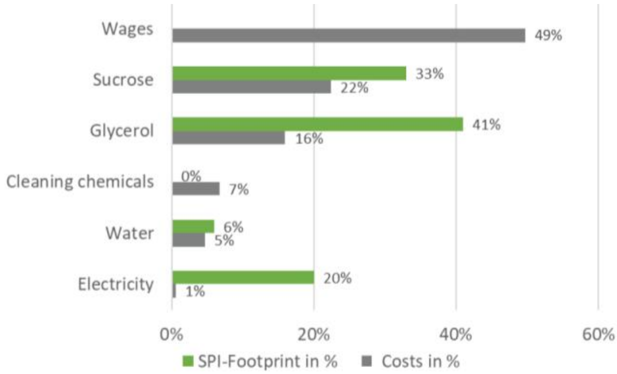

Fig. 5 Main contributors to economic and environmental burden of the biocatalytic synthesis unit operation in biotechnological glycoside production (biocatalyst fermentation was treated as separate process unit and is not included here)

From an economic point of view, the highest cost items are of particular interest. However, the evaluation of the optimization potentials was also carried out under environmental aspects, so that not only the effects of a cost optimization, but also a sustainable optimization was considered (Janz & Westkämper 2007). For example, it was revealed that the electricity had previously been purchased from a fossil-fuel power generator. The environmental footprint was therefore high. The following example of visualizing combined economic and environmental evaluation results clearly shows that the optimization measure "switch to green electricity" has a low economic but high (positive) environmental impact.

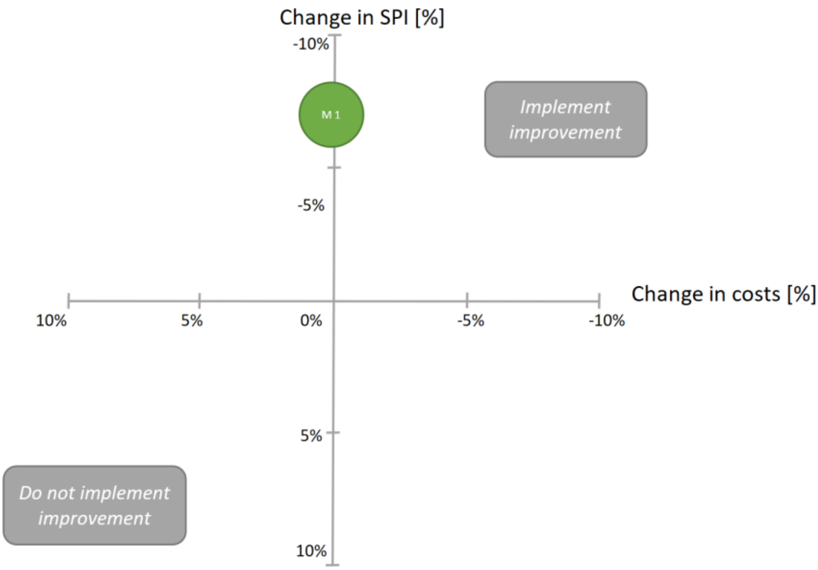

Fig. 6 Presentation of the change in costs and sustainable process index (SPI) for the optimization measure of electricity switching from conventional to sustainable supplier mix for the biocatalytic synthesis step in glycoside production.

Figure 6 shows an application example for a recommendation to reduce the environmental footprint. Switching the electricity supply for the process from conventional electricity to green electricity results in a reduction of the overall environmental footprint of the hot spot process step “biocatalytic synthesis” by 7% (from 20% in the reference process to 13% in the process switched to green electricity). This measure is accompanied by higher electricity costs. Green electricity is 30% more expensive than conventional one in our example. When looking at electricity prices alone this might be interpreted as a too high increase to implement. However, a combined presentation of impact on total costs as well as total environmental burden makes clear, that increase in total cost by 0.2% is marginable and should be considered for implementation when aiming at more environmentally friendly processes.

For the application in companies, optimisation means that each improvement proposal, which was mentioned in an improvement plan, must be examined with regard to the change in the cost and environmental impact situation and it must be assessed individually for each measure whether it should be implemented or not. In practice, a representation method for suggested measures which allows easy visual capture of the impacts will be highly advantageous for this decision process.

5. Conclusion

This paper presents a procedure how to assist optimization of processes taking into account the environmental and economical perspective. The focus is on a practical approach to how technical improvement proposals can be presented. The 4-quadrant matrix can be used to show visually and transparently how changes in the process affect the environmental footprint as well as cost. The starting point is the original process, which represents the origin in the presented graph. The respective technically feasible changes are evaluated by the controlling department and the induced change in total footprint and cost is displayed in the diagram. This provides management with an easy to capture basis for deciding whether the proposed measures should be implemented in the company.

A theoretical limitation of the method can be seen in the nature of the SPI calculation method used for environmental impact evaluation. Although this has the advantage that a single value, namely an increase or decrease in overall environmental footprint represented as an area value, is calculated, a differentiation of impacts in single impact categories (such as climate change, eutrophication, water depletion etc.) is disregarded.

In the case of the LCC-model, the validity of future income and expenditure in particular causes problems. With an assumed long life cycle, the future figures are fraught with uncertainty. This affects the extrapolation with the existing indices. Furthermore, suitable indices do not exist for all cost types in order to make the price adjustments.

The practical limitations are that the information for the valuation of the individual measures is usually difficult to obtain. In the above mentioned project, for example, it became apparent that the primary data for cost and life cycle inventory could only be obtained with great difficulty and effort of industrial partners. A careful assessment of the data quality should therefore accompany impact evaluation and could in future be included in the here described method for presentation of economic and environmental optimization potential.

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INTERNO IZVEŠTAVANJE O MERAMA ZA OPTIMIZACIJU PROCESA: KOMBINACIJA EKONOMSKIH I EKOLOŠKIH ASPEKATA

Optimizacija troškova je deo svakodnevnog poslovanja kompanije. Razvijeni su brojni instrument ii metodi za izračunavanje potencijalnih ušteda i njihovo saopštavanje donosiocima odluka. U budućnosti, kako bi kompanije poslovale održivije, neophodno je da se mere optimizacije sagledavaju sa ekonomskog *is a ekološkog stanovišta. Ovaj rad predlaže da se izveštaji dopunjavaju matricom koja ekonomske i ekološke uticaje stavlja nasuprot pojedinačnih mera optimizacije. Ovakav način izveštavanja bi trebalo da pomogne donosiocima odluka u odabiru mera optimizacije, uzimajući u obzir ekomonske i ekološke aspekte. Kao studija slučaja uzeta je procena LCA i LCC-bazirane evaluacije biotehnološkog procesa za proizvodnju glikozida. Pokazan je primer prezentacije uticaja prelaska na održivi električni miks.*

Ključne reči: *izveštavanje, poboljšanje procesa, LCA, LCC, LCA/LCC kombinacija, ekonomske i ekološke performanse, održivost,CARBAFIN*

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Original Scientific Paper

THE COMPLEXITY PARADIGM: TOWARDS A MODEL FOR THE ANALYSIS OF SOCIAL SYSTEMS AND PROBLEMS

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Abstract. *The article proposes the complexity paradigm as an innovative reasoning for analyzing problems in behavioral sciences. It begins to explain the contributions of the major authors of the complex reasoning paradigm: Gödel, Prigogine and Morin. They offer the basis to a model of analysis and assessment of complex systems and problems (ACSIP Model). The four postulates of the Model are explained, emphasizing the principal hypothesis of the Model – the level of cognitive operations is the most important factor of complexity of a system; then to understand it, the cognitive level of analysis must be at minimum equal to that of the system or the problem under analysis. In the second part the article, an illustrative application of the ACSIP Model is applied to the analysis of the SDG 9 from the UN 20/30 agenda, showing the analysis of a complex problem, guided by the complexity reasoning model. Following that, an empirical research is presented, to verify the hypothesis underlying the fourth postulate of the model. The results confirm the hypothesis: the use of information by a group is inversely proportional to the use of power (authority). These results allow us to conclude that the complex reasoning paradigm is a promising tool to obtain synergic results in the scientific analysis and resolution of concrete social problems and to face the complex challenges brought by artificial intelligence systems.*

Key words: *Morin's operators; Cognitive complexity; ACSIP Model; Socioeconomic inequalities; Results synergy*

JEL Classification: I32, J18

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1. INTRODUCTION

The article explores the complexity paradigm as an innovative reasoning for analyzing social systems and problems, taking into account that they are usually quite entangled and requiring an interdisciplinary approach. The article has as its main objective the formulation of an analysis model based on the complex reasoning paradigm and the explanation of its core postulates and its interdisciplinary and multi-level analysis of social problems. To accomplish this purpose, we begin to record the path of the complexity idea in Psychology and other behavioral sciences, before advancing to the work of the authors who are the pillars of the complexity paradigm in present scientific realm.

Psychology addressed the problem of human cognitive complexity, as early as 1955: Bieri (1955) was concerned with cognitive complexity and its effect on predictive behavior; Kelly, also in 1955, investigated the cognitive complexity in the structuring of personality; Nidorf and Crockett (1965), Karlins et al. (1967) and Schröder (1971a) continued these studies, exploring the effect of cognitive complexity on creativity, conflict resolution and the structure of personality, while others oriented themselves towards the integration of complex thinking into the area of organizational behavior: Mitchell (1971), studied the effect of cognitive complexity on team productivity; Streufert and Streufert (1978) and Streufert and Swezey (1986) explored the impact of context complexity on organizational behavior.

These studies address problems from a variety of models, but they all have some common bases:

- our mind is made up of interrelated cognitive processes, responsible for the organization of our knowledge;
- these cognitive processes occur in a certain order, albeit flexible; but the concern with the method, a core issue in addressing the cognitive complexity (Neufeld and Stein, 1999), is an evident trait;
- they are not restricted to their neurological support substrate, although they depend on it and its organization: the mind is a processor of symbols and meanings, which are related to the objects of the context;
- the human relationship with the external world is, therefore, intentional and autonomous.

The integration of the complexity paradigm in Psychology was continued by the work of authors such as Hooijberg, Hunt and Dodge (1997), Lichtenstein and Plowman (2009), Schneider and Somers (2006) or Uhl-Bien and Marion (2007), on leadership complex models and complex systems organization. The contribution of Psychology to the understanding and application of the paradigm of complex thinking cannot be ignored (Streufert, 2006); and the willingness of these psychologists to adopt different explanatory models, recognizing that the notion of complexity needs multiple approaches, in order to be fully understood and explained, expanded to other social sciences – mainly Sociology and Economy. We cannot forget the contribution of scholars of economic organizations, such as Herbert Simon, with their works on the limited rationality of our decisions (Simon, 1987), as well as on the architecture of cognitive complexity (Simon, 1962); von Neumann for his studies on cybernetic systems; the work of Albin and Göttinger (1983) on the complexity in the economic area; chemical and biological scientists such as Prigogine and his colleague Nicolis (1989); and sociologists such as Edgar Morin (1977; 1990; 2001; 2011) and Le Moigne (1999) in social sciences epistemology. All these authors pave the ground which nourishes the complex reasoning paradigm, and mainly those who are the pillars of

Model proposed in this article: Gödel, Prigogine and Morin. On the basis of these authors' ideas about the factors of systems complexity and the tools of complex reasoning, a model is formulated (ACSIP- Analysis of Complex Systems and Problems), with an interdisciplinary and multi-level view of social problems. Its aim is to understand the factors of systems complexity and their dilemmatic relationship, and to allow us to manage them at the cognitive level required by their complexity, in order to avoid any perverse effects, frequently observed, when interventions are not guided by the appropriate level of knowledge.

2. On the Shoulders of Giants: the Three Pillars of a Complex Reasoning Model

As it was stated by Bernardo de Chatres[2], if our eyes can reach very distant horizons, this is due to the fact that we are seated on the shoulders of giants, those thinkers who opened our way to the knowledge we enjoy today: the three referred authors who are at the source of the complex reasoning paradigm and who established its pillars and mainstays.

2.1. Gödel's foundational work

The complexity paradigm, whose first foundation can be found in the work of Kurt Gödel (1931) on the incompleteness of the demonstrability of propositions recognized as true within a logical system, received theoretical contributions over time, from several authors. His work on the demonstration of the undecidable propositions and the formulation of the incompleteness theorems had a discreet repercussion; but it was the first stone of the new style of thinking that would come to be affirmed throughout the XX century, in several scientific domains. Beyond its repercussion on logic and mathematics, the idea of complexity impacted also on cognitive and social psychology and its interventions on organizational behavior: decision theory and cybernetic systems (Simon, 1962); research work on biological systems (Prigogineand Stengers,1997); studies on the complexity of economic processes (Albin e Göttinger, 1983); the work of sociologists like Le Moigne (1999), and psychologists, mainly from the area of Cognitive Psychology (Bieri, 1955) and Kelly (1955) and organizational behavior (Mitchell, 1971; Streufert and Streufert, 1978). In a tribute article on the centenary of Gödel's birth, Alkaine, says that Gödel's work shows the limits of reason, and therefore they should "be taken into account in modern areas of the exact sciences, since these works "greatly affected the way we think today" (Alkaine, 2006, p. 526). Gödel showed that the appearance of paradoxes in mathematics is inevitable; and to keep the system consistent with itself they must be accepted as undecidables: "propositions that cannot be decided as false or true within the system itself, but only from an external conceptual field. This is the price to pay for the consistency of the system" (Kubrusly, 2006, p.8). As Gödel argued at the Königsberg Congress on Epistemology of the Exact Sciences,

(1) If a formal system containing arithmetic is consistent, then it contains true arithmetic propositions which, however, are undecidable;
(2) There is no computable procedure to prove the consistency of the theory within itself (Lannes, 2014, p.4).

[2] It seems to have been Bernard of Chartres the father of the sentence which Newton (quoted in Hawking, 2003) made famous in a letter to Hooke " If I have seen further, it is by standing on the shoulders of giants".

The truth or falsity of an undecidable, will always have to be based on a more comprehensive and less restrictive logic than that adopted for the mathematical system in question (Kubrusly, 2006). The impact of these two theorems turned out to be a liberating influence, when they triggered a new style of thought in epistemology (Fleck, 1979, quoted in Lannes, 2014); and this impact led precisely to a change in attitude towards the realm of science today, the arguments with which we intend to affirm it, their limitations and even the weaknesses of their roots.

Gödel's work showed that the logical foundation of an interpretative system of reality has to be sought in a conceptual system in a broader rationality. This requirement places Gödel as a primary source of the complex thinking paradigm, as it becomes visible in the letter from von Neumann to Gödel (quoted in Ferreira, 2006, p. 1):

I must testify all my admiration (...): you solved this enormous problem with masterly simplicity (...) to show that the consistency of mathematics is not demonstrable (...) Reading your study was really an aesthetic experience at the highest level.

This article aims to highlight the impact of this new style of thinking and transpose the practices which it recommends into the domain of the social sciences (Lannes, 2014). To do it, it explores the contribution of thinkers who are the pillars of the complexity paradigm and led to the change in attitude that is the heart of scientific thinking today.

Prigogine is responsible for some fundamental ideas that helped to broaden the horizons of scientific thought towards the incorporation of the idea of complexity, by his proposal of three main ideas:

- the end of certainties in science;
- the idea of bifurcation, which opens possible alternatives of structuring, based on the condition of unstable structures (dissipative structures), leading to more or less extensive changes;
- the irreversibility of time linked to the former concept, which enriched the meaning of the change processes with the idea of history.

2.2. Prigogine's contribution

Prigogine is responsible for some fundamental ideas that helped to broaden the horizons of scientific thought towards the incorporation of the idea of complexity, by his proposal of three main ideas:

- the end of certainties in science;
- the condition of unstable structures (dissipative structures) as a source of more or less extensive changes;
- the idea of bifurcation, which opens possible alternatives of structuring things, linked to the concept of time irreversibility, which enriched the meaning of the change processes with the idea of history.

2.2.1. The end of certainties

The end of certainties does not mean for Prigogine the empire of ignorance; what he underlines is that this new vision leads us to leave aside "the tranquil certainties of traditional dynamics" (Massoni, 2008, p. 2308-7). In place of them, to broaden their scope, Prigogine proposes that science incorporates indeterminism, which acquires a precise meaning: it is not the absence of predictability, but the knowledge of the limits of predictability (Prigogine, 1997): it expresses not what is right, but what is possible; and this possible is the new meaning of the laws of nature (Massoni,2008). Consequently, determinism breaks down, because everything is in motion in this universe of complex systems, with multiple possibilities open to the system (Prigogine, 2009). That is why the probability is directly linked to uncertainty or, if the term is preferred, to indeterminism.

On the other hand, the questions addressed in science are not eternal, they are linked to a determined historical time (Carvalho, 2014), they result from the questioning of previous knowledge and the growing disillusion caused by the answers it offers (Bachelard, 1940). This is the end of the neutral and seemingly timeless certainties, not the end of knowing which is complex. It only breaks the symmetry of temporal reversibility and integrates entropy as one of the indicators of the irreversibility of time. The awareness that the field of current science is not that of the tranquil certainties of classical determinism gets stronger: the new state of matter (far from equilibrium, which cannot be described by linear equations) forces us to see under another light the world around us, the phenomena of life, of time, of the multiplicity of structures. Scientific reasoning leaves the field of bounded certainty of linearity (Simon, 1962; 1987) and enters the territory of the multilinear possibilities to be explained, in line with Gödel's undecidable.

2.2.2. The idea of dissipative structures and bifurcations

Prigogine considered bifurcation the most important characteristic of complex systems, because “bifurcation is the critical point through which a new state becomes possible in nature” (Prigogine & Stengers, 1997, p. 122). Bifurcations arise from two moments: disordered and turbulent movements due to forces that cause a state of imbalance in the system and push it to the edge of chaos; creation of dissipative structures of the energy which causes the state of imbalance. The dissipative structures allow order to emerge from chaos, from entropic movements, through the entrance of the system in one of the possible bifurcations open to the future[3]. “Each complex being is formed by a plurality of entangled times. In this way, history, as a process - of a living being or of a society - can never be reduced to the monotonous simplicity of a single time” (Prigogine & Stengers, 1997, p. 211). In the succession of bifurcations, deterministic zones alternate between bifurcations and points of probabilistic behavior, the bifurcation points; in these bifurcations there are generally many possibilities open to the system. The appearance of the new structures is rooted in the energy-dissipating structures. This emergency implies time in a defined direction, which led Prigogine (1980) to assert that the logic of irreversible processes of systems far from equilibrium is not a logic of equilibrium, but a narrative logic, that is the activity of dissipative structures is defined as history and not just as a balance of energies. The result is a breakdown of determinism, even on the macroscopic scale (Prigogine & Stengers, 1984).

The multiple possibilities open to the system cannot be reduced to a single scheme (Prigogine & Stengers, 2009). The system can never be explained based on the simplicity of a single time path: it became complex, as it is constituted by a plurality of times in which past, present and future are interwoven. Any state the system is not something that can be deduced, as others were also possible. The explanation must be historical or genetic: to describe the path that constitutes the system's past, enumerate the bifurcations

[3] The challenge put by the COVID-19 pandemic is an example of an event at the edge of chaos, which forced the emergence of cooperative behavior even between political adversaries, more, between nations “geopolitical competitors”. It may contribute to the emergence of a new world order.

crossed and the fluctuations that decided the real history, among all possible ones (Prigogine & Stengers, 1997).

Bifurcations introduce time as a fundamental variable: time no longer can be ignored, even in physico-chemical ones, where entropy is the indicator of an irreversible temporal movement. Eddington (1928) called it the arrow of time, because it indicates the degradation of the energy and the matter that constitute them. In living systems, which in addition to energy and matter exchange information with the environment, the emergence of new states (negentropy, as Morin designed it) is another indicator of the arrow of time[4]. The arrow of time is the way we experience it, a subjective perception of what we ourselves are: the irreversibility of time is a function of movement in a finite system, subject to entropy processes, whose logic is that of narrative, not that of symmetrical balance. To know a complex system requires to know its past and calculate its future, based on a careful view of its past and present (Prigogine, 2008). The system is a totality of time[5].

The multiple choices in the bifurcations define the degrees of freedom and intrinsic creativity of complex systems and force us to incorporate uncertainty as a component of knowledge, no longer as a negative posture, but as a way of seeing reality. A way more attentive to its multiple plans, more open and questioning, in which the certainty of what is known contains the awareness of its limitation, of its uncertainty, typical of all finite systems (Tarsky, 1933, quoted in Sher, 1999, p.150).

By scientifically contributing to the end of limited and limiting certainties, Prigogine continued Gödel's reflection on the inherent limitation of logical systems and the need to move up to higher conceptual systems, as a condition for understanding complex realities. Studying the emergence of order from states close to chaos, due to the dissipative energy structures and the opening of bifurcations, Prigogine took a decisive step to explain the changes which lead to the emergence of new structures and new meanings, an essential component of the dynamic complexity of the systems. Finally, with the idea that time is an irreversible path for living systems and that these can only be understood as complex history, Prigogine introduces another essential factor for complexity, in line with the dialogic and recursive principles, proposed by Morin to understand the circular processes that build the total complexity of the systems.

2.3. Morin's fundamental contribution

Edgar Morin is the most notorious author associated with the complex reasoning paradigm (Morin, 1990). According to him, all human activity obeys a tetralogy of relationships: order, disorder, interaction, (re) organization (Morin, 2011). Order and

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[4] In physico-chemical systems, subject to the second law of thermodynamics, entropy is the indicator of the arrow of time (Eddington, 1928), because it marks the degradation of their energy and matter; in living systems, which exchange not only energy and matter with the environment, but also information, bifurcations and the emergence of new states (negentropy) are the second indicator of the arrow of time. The idea of the irreversibility of time may seem to contradict the position of Bradford Skow (2015), who defends the idea that all times are coexistent in the universal fabric of time: this is one of the constituents of the universe, and past, present and future would coexist in that fabric. But there is no contradiction: the arrow of time is the way we experience it, a relative perception, subjective to what we ourselves are. We can say, with Prigogine, that the irreversibility of time is a function of the movement in a finite system.

[5] Quoting Heidegger (1977), if the Dasein, the living human system, is a being to death, only in the end of his irreversible time, his own history, he can resolve the anguish of his existence, having reached his completeness and no more changeable identity (his totality as Dasein is now fixed).

disorder must be understood as a pair in dialogical relationship, which produces new configurations, based on the interaction of the parties and their reorganization. In this process, cause and effect interact in a reciprocal movement, which is opposed to the simplicity of linear causality: time allows the feedback of the effects on their causes, forming a multidirectional complex causal circle. The complexity of a system results, therefore, from the multiplicity of its conditions and the variety of its movements (interaction and reorganization). The internal diversity of a system, the variety of its component parts, can be considered the first criterion for assessing complexity (static complexity); the variety of the internal movements adds to the diversity of the parts in the construction of complexity, as stated by Kochugovindan and Vriend (1998, p.56): "complex systems are based on a large number of agents, who interact with each other in various ways and modify their actions as a result of the events in the interaction process " (dynamic complexity).

To understand the complexity of the real, Morin proposes a method, which he himself rooted in three theories (Morin, 2011): the systems theory, and the idea that the whole is superior to its parts, since it exhibits emerged qualities; information theory, which places us in an universe where order and disorder coexist, where information has the role of creating new realities; cybernetics, which highlights the feedback processes: one (negative feedback), responsible for the stability of the system; the other (positive feedback), responsible for their change. From these roots, Morin elaborated the methodological principles of complex thinking, which constitute the framework of what he called the paradigm of complexity and proposes as an instrument for understanding the real. In his words,

> disorder, translates into uncertainty (...) it brings chance, inevitable ingredient of everything that appears to us as disorder (...) every order process occurs due to a greater disorder - related to the second principle of thermodynamics (...) agitation, the encounter at random are necessary for the organization of the universe and that it is disintegrating that the world is organized - this is a typically complex idea because it unites the two notions, order and disorder. A strictly deterministic universe would be just order, it would be a universe without innovation, without creation (Morin, 2001, p.87).

The logical requirement for this way of reasoning must be greater than that of any simplifying thinking:

> it is evident that a reality that is organized in a complex way requires, for your understanding, a complex thought, that ... must go beyond the closed entities, isolated objects, clear and distinct ideas, but also not to be confined in the confusion, in the vaporous, in the ambiguity, in the contradiction: it must be a game / work with / against uncertainty, imprecision, the contradiction (Morin, 2001, p. 87)

Morin (2011, p. 141) uses this logic in the tetralog, to explain the recursive circuit: complementary (societies, associations, mutualisms), competitive (competitions and rivalries) and antagonist (parasitism, depredation) relationships:

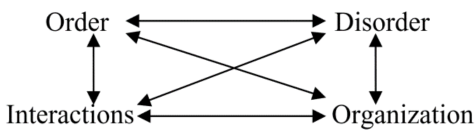

Fig. 1 The tetralog
Source: Morin (2011, p141)

The idea of complexity does not intend to replace concepts like clarity, certainty, determination and coherence by those of ambiguity, uncertainty and contradiction: it is based on the interaction and mutual work between such principles (Morin, 2001, p.88). It requires a strategic vision (not only tactical or operative) which Morin defined as the art of "using the information that emerges during the action, integrating it, formulating action plans and being able to gather as many certainties as possible, to face the uncertain". (Morin, 2001, p.90).

To put the tetralogic ring into practice, Morin proposes three conceptual operators: *dialogic, recursive, holographic*.

2.3.1. The dialogic operator

The dialogic operator (which Morin views as superior to the concept of dialectics) consists in identifying the different parts of the system as accurately as possible, to link what seems separate or even contradictory. The systematic use of the dialogic operator is fundamental to think the real, to apprehend it in its unity and multiplicity, not trying to explain it by its particular elements, which are reducing. This will help us to arrive at a "true, open rationality dialoguing with a reality that resists it, a rationality aware of its insufficiencies" (Morin, 2011, p.23). To do so it is crucial to understand the diverse and elaborate the concepts that allow to build the *unitas multiplex*: the unity of the whole which does not suppress, but on the contrary takes advantage of diversity.

2.3.2. The recursive operator

The recursive operator is related to negative and positive feedback processes proposed by Wiener (1961). To Morin, recursive causality is not limited to regulating processes or expanding deviations; it is ontological, it is an instrument for constructing the complex system itself:

> At a higher level, recursion is translated by consciousness, the last emergence of complexity, specific of the human spirit (...) consciousness is reflexive, implies an unceasing return to the thoughts that produce it, to transform them ... providing the faculties of doubt, of self-examination…consolidating in ourselves the uniduality of the observed subject and the subject who observes (Morin, 2011, p.143).

It is not a linear relation – cause→effect - but it is about understanding the interactions that unfold the system and make it evolve, in the whole and in its parts, as it builds itself along the arrow of time (an arrow in spiral, where setbacks are present overvaluations of the weight of past causes).

2.3.3. The holographic operator

According to Morin himself, the idea of this operator came from systems theory and directly from the contact with Atlan and his ideas about self-organizing chance and the autopoiesis of complex living systems (Atlan, 1994). The self-organization of the system as a whole results from the emergence of integrating components and qualities, through the recursive process. So, holographic reasoning requires an effective knowledge of these components and the perception of their contribution to a different whole, which receives meaning from its parts, but which also gives to each of them a sense of their own. The whole is not a *pot pourri* of confused ideas, but the clarity of the particular in the whole and the clarity of the whole in the particular. It is the effort to understand the complexity of a real that can only be well understood in this dialogical junction of opposites.

Thinking the real and a knowledge based on these operators is at the heart of Morin's ideas about complexity. His reflection includes the essential epistemological acquisitions of the authors who have explored this paradigm:

- the lesson of Gödel's paradox: to explain a complex phenomenon one has to look for knowledge outside it (in the context, in higher-level models); otherwise, the system will always contain undecidable propositions, which we believe to be substantiated, but which cannot be demonstrated within the system;
- the concept of dissipative structures, from Prigogine, that allow to understand the emergence of a new order with a new meaning, expressing the dynamic complexity of the system;
- the belief that humans must be operators of complexity, capable of overcoming a mere intra-disciplinary reasoning and building a multidimensional, interdisciplinary science;
- the idea that information is the tool for reflexivity, self-reference, creativity, because it is the articulating axis of the constructed real (subject-object): it "allows us to move beyond the paradigm of classical science and logic, without rejecting them, but integrating them in the paradigm of complexity "(Morin, 2011, p. 151). This opens a door to other levels of reality (Nicolescu, 1999) and new insights, in the spiral path of knowledge construction.

Morin's reasoning is completed by Kaufmann (1993; 1995) and Gell-Mann (1994), who advance in the elaboration of an operational model of complex reasoning.

Kaufmann argues that complexity is based on four variables: N, number of system components; K, the level of components interactions; P, the common elements between the components which ensure the emergence of the totality; C, the interactions of the system and its components with other entities in the context. Gell-Mann emphasizes the role of information in defining the level of complexity, pointing out that the complexity of a system is a function of the difficulty in describing it, verbally or mathematically, making explicit a fundamental aspect of the concept of complexity. With this Gell-Mann explains a fundamental aspect of the concept of complexity, already touched on by Morin and anchored in Gödel's incompleteness theorem.

3. A Complex Model for System and Problem Analysis

Starting from the ideas proposed, four postulates are delineated, which define a complex reasoning model, for the analysis and evaluation of systems and problems in human and social sciences. The first postulate of the Model defines the static (structural) complexity of a system and is based on:

- Morin's idea that the whole is more than its parts (it has properties that emerge and are not in them), but it is simultaneously less than its parts (constituting itself as such, it inhibits potentialities inherent in the parts that constitute it);
- Kaufmann's (1995) idea that the complexity of the system is determined by the number of parts that make it up.

First Postulate - The greater the number of different parts of a system, from which its global identity emerges, the greater is its complexity (static complexity).

The Second postulate combines Prigogine's ideas - the emergence of new configurations in systems far from equilibrium (due to the dissipative structures of energy and the bifurcations they open in time) - and Morin's ideas about recursive processes and the tetralogic ring (the interactions that create order/disorder, organization/disorganization). But, in addition to these movements of internal dynamics, there is the external dynamics of interactions with the context, which integrates physical, economic, social, cultural, political factors. These movements as a whole define the dynamic complexity of the system.

Second Postulate - The internal and external movements of the system define its lived history, subject to the process of irreversibility of time, whether they are entropic or negentropic movements. The greater the variety of these movements, the greater, ceteris paribus, the complexity of the system (dynamic complexity).

There is yet another criterion to define complexity: the level and mode of integration of diversity in a system with its own identity. The system is not the mere sum of its parts, it is built as a unitary whole, continually emerging from the interaction of these parts, integrating the nature of each one in a new nature, its own as a system. That is why Morin called it unitas multiplex, a unit of multiplicity:

> The unit of the system is not the unit of unum, it is simultaneously one and not one. There is a loophole and shadow in the logic of identity. We have already seen that there is not only diversity in the one, but also relativity of the one, otherness in the one, uncertainties, ambiguities, dualities, splits, antagonisms (Morin, 1977, p. 140).

The processes of articulation and integration of these parts, leading to distinctive patterns of behavior, are, therefore, nuclear. The integration of diversity in the unit can be achieved through two processes: the use of energy (power, in human systems); and information, which articulates diversity, through the discovery and use of adjustment processes that take advantage of it. Morin extensively advocates the role of information in building complexity. In his matrix idea, obtaining the unity of a system through the use of power leads to a more or less extensive reduction in diversity, because the unification by the use of power forces us to homogenize what is integrated; building unity and simultaneously maintaining diversity is only feasible by learning new and more comprehensive ways and by exchanging information, until a suitable format is found. This new format, therefore, necessarily integrates more information than the previous ones. This is the idea that supports the third postulate of the Model.

Third Postulate - The more the emergence of the identity of a system from its components is carried out through information and not power processes, the greater will be its internal variety, the higher the informational level of interactions and, consequently, the complexity of the system.

Thus, the substantive complexity of a system can be assessed on the basis of its position in the criteria established by the postulates. Similarly, an explanatory model based on these postulates is an instrument for the operational use of complex reasoning, the main challenge of this article: to build a model of cognitive complexity suitable for the analysis of complex systems and problems that we face in the social sciences area. The fourth postulate takes up the idea of Gödel's undecidables and expresses the cognitive conditions of the complex reasoning paradigm, highlighted by the Gell-Mann criterion: the complexity of a system is all the greater the more difficult is its verbal or mathematical description.

Fourth Postulate - To understand a system or to solve a problem with a certain level of information complexity, it is required a cognitive complexity, at a level equal or above the informational complexity of the concerned system or problem.

The figures 2 and 3 show the interactions between the model's variables and present the basic formulas that express them.

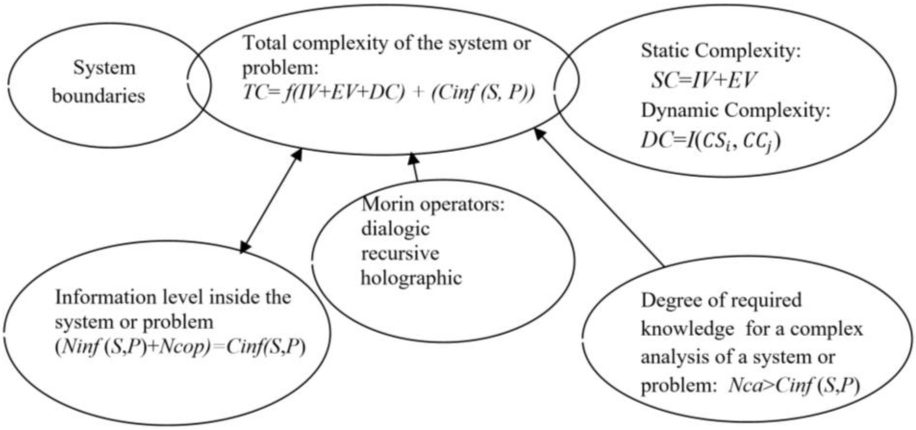

Fig. 2 The ACSIP Model – complex analysis of systems and problems
Source: authors

Where:

$IV = \sum_{i=1}^{n} CS_i$ – internal variety of the system or problem

CS_i – i = 1,...,n the systemcomponents or the dimensions of the problem

VE – external variety of a system $VE = \sum_{j=!}^{m} CC_j$

CC_j – j = 1,...,m – context components interacting with the system

CD – system's dynamic complexity (which varies over time)

$CD = I\ (CS_i, CC_j)$, so as I – competitive interactions and resolutive interactions

S – system

P – problem

Cinf (S, P) – information complexity of the system or problem

Ninf (S, P) – information level inside the system or the problem, which includes *gi* (S, P)

gi (S, P) – interdisciplinarity degree inside the system or the problem

Nca – level of knowledge at what analysis is conducted

$$1\text{- } Cinf(S,P) = f(Ninf(S,P), NCop)$$

$$2 \text{ - } CCR > Cinf(S,P)$$

$$3 \text{ - } NCa \geq CCR$$

Where:

CCR - cognitive complexity required for a complex analysis

$Cinf(S,P)$ - information complexity of the system or problem: the information complexity of a system or a problem is a function of its information level *Ninf(S,P)* and of the cognitive level at which it operates (*NCop*)

NCop = cognitive level of a system's operations, measured by its comparison to the academic degrees: 1 - ≤ 9 years; 2 - 12 years; 3 - BAC.; 4 - master; 5 - PhD; 6 - post-doctor

Nca = cognitive level of analysis (as in *NCop*)

Fig. 3 Formulas for the required complexity of analysis
Source: authors

The first formula expresses the complexity of a system or a problem as defined in the first three postulates of the ACSIP Model: it is derived from the combination of the number of different components of the system or the problem (VI); the internal movements of these components; external movements in the system's relationship with its context; and the informational level inherent in the system and its operations (*Ninf* (*S,P*)). The second and third formulas are directly related to the fourth postulate of the Model: the second defines that the required cognitive complexity has to be greater than that of the system or the problem (*CCR* > *Cinf* (*S,P*)) to be capable to understand and explain it; the third indicates the requirements to be met (*Nca* ≥ *CCR*), so that the analysis of a complex system or problem can resolve them.

4. Entering into the Practice of Complex Reasoning

We enter now into the empirical part of this study: the impact of several power conditions on the operationalization of information by problem-solving groups is evaluated, to test a hypothesis (H1) related to the postulates three and four of the Model: *the use of useful information for the analysis and resolution of problems is all the greater the less the power used in the interactions between the leader and the group and among members themselves*.

Secondly, the operationalization of the ACSIP Model is shown, using an example of the analysis and decision of a complex problem, posed by the SDG 9 of the UN 20/30 agenda, 2017.

At the individual level, cognitive complexity requires to develop an interdisciplinary attitude, with the perception of the divergent and the ability to ask and dialogue with divergent knowledge views. To achieve this attitude, sufficient emotional self-regulation is required (Bar-on, Maree & Elias, 2007), based on the well-known criteria of emotional intelligence (Goleman, 1996):

At the individual level, cognitive complexity requires mainly to develop an interdisciplinary attitude, with the perception of the divergent and the ability to ask and dialogue with divergent knowledge views. To achieve this attitude, sufficient emotional self-regulation is required (Bar-on, Maree & Elias, 2007), based on the well-known criteria of emotional intelligence (Goleman, 1996):

- the self-regulation of emotions allows to increase the quantity and diversity of descriptors used in explaining the real, and better encompass the internal and external variety of the analyzed system or problem (Kaufmann, 1995);
- the increase in the variety of descriptors raises the level of interpretations, as it increases the ability to integrate divergent or contradictory information (Morin's dialogic operator; Gell-Mann’s proposal);
- the level of precision in the use of descriptors makes them operationally more effective, explaining more completely the global identity of what is analyzed, and its context (Morin, 2001).

But today, scientific and technical interdisciplinary analysis cannot be individually guaranteed: it requires the support of a team that accepts that diversity and builds interdisciplinary models of high enough level to integrate diverging views, without distorting them. To ensure an open discussion and the exchange of useful information, the analysis team must be conducted by a participative leadership centered on the search for information[6] (Parreira, 2010), excluding or greatly reducing the usual forms of power.

However, the complexity required to the human subject goes beyond the purely cognitive domain. Interventions in nature and society, without adequate knowledge of its impact on reality, can lead to dangerous, often not realized, changes. Actually, intervening on the real implies using technology and technology is mainly power, requiring an accurate knowledge of its potential effects. It is a challenge to the human operator: all these studies and the proposed Model point to the advantage of increasing the complexity level of reasoning in people, teams and organizations; but, as Streufert and Strufert (1978) state, the training of cognitive complexity, although difficult, is possible.

4.1. An empirical test of a hypothesis related to the third and fourth postulates

The use of the highest level of information available is essential for an analysis covering the complexity of the problems to be resolved. The hypothesis (H1) to be tested is derived from the stated postulates.

H1: the use of useful information for the analysis and resolution of problems is all the greater the less the power used in the interactions between the leader and the group and among members themselves.

To test H1, a questionnaire survey was carried out, with a sample of university teachers and students, with the objective of measuring the impact that the use of power by the leader and members of a group could have on the utilization of information, when analysing and finding solutions for problems faced by the group.

4.2. The instrument

The instrument used in the research was a questionnaire in the format of a semantic differential; this format was chosen to make it easier for respondents to simultaneously

[6] Participatory leadership is used here in the definition of the Multiplex Model (Parreira, 2010): leader-group interactions are extensively of a resolutive and non-competitive type; using restricted power, varying only with the task and preparation of the group, always privileging information as asked by Morin.

consider the two types of possible impact (positive and negative) associated to the power behavior pattern. Responses are given on an interval scale based on adverbs of quantity (each adverbial position has a numerical value established in studies carried out since 2003).

The questionnaire has construct validity, since the items describe situations presented in the studies of the classic authors on leadership and power (Day, 2014), and are part of the experience of people in different work contexts. In addition, the questionnaire was subjected to a pre-test in three groups of people of different profession and education (over 12 years of schooling), and their observations led to modify some aspects of the wording describing the stimulus situations.

Six situations are presented, and respondents evaluate the possible impact of the power described in each one on the operationalization of information; the evaluations are made in the above referred scale. It is written in Portuguese and translated into English, in this paper.

4.2.1. An example of the initial instructions and the two extreme situations

Probably you have already experienced situations where the leader and the group members used to a greater or lesser extent attitudes of power and authority, to make the group accept the solutions they proposed; in other situations, this pressure was less or almost not used. Please pay attention to the situations presented below and try to assess to what extent attitudes of power in the group have a negative or a positive impact on the use of useful information to resolve the problems.

If you think that the behavior described in the situation has a negative impact, please mark X in the adverb that best corresponds to your idea, in the left branch of the scale; if you consider that the described behavior has a positive impact, mark X in the adverb that best corresponds to your idea, in the right branch of the scale. If you have no idea about the possible impact of the described behavior, mark X in the box "I can't decide". All answers are correct, as long as they express what you actually think.

Table 1 The two extreme situations presented in the questionnaire

1. The leader and group members used extremely competitive attitudes and enforced their ideas, when analysing problems and discussing solutions to them. It was extremely difficult to convince them to analyse any idea divergent from their own.								
Negative	Impact of the described behaviors on the use of information							**Positive**
Extremely	Very much	Medially	Little	I can't decide	Little	Medially	Very much	Extremely
Situations 2, 3, 4, 5								
6. The leader and group members almost did not use competitive attitudes nor imposed their ideas, when analysing problems and discussing solutions to them. Their attitudes were very open and everyone always accepted to analyse and discuss any solution, even if it was divergent from his own.								
Negative	Impact of the described behaviors on the use of information							**Positive**
Extremely	Very much	Medially	Little	I can't decide	Little	Medially	Very much	Extremely

Source: authors

The used scale, expressed in quantity adverbs may be an example of the fruitful synergy between qualitative and quantitative methods: it is a mix of a qualitative expression (adverb), used currently to evaluate objects and situations, and a quantitative measure (numerical interval scale), based on the numerical value attributed to the adverbs and adverbial expressions, in studies carried out since 2003 (Parreira & Lorga da Silva, 2016).

The authors believe that this enhances the validity of the scales, namely because they are not a mere ordinal but an interval scale (between nothing at all (=0.54) and extremely (9.25), the values obtained in the referred studies The qualitative-quantitative mix is reinforced by the description of situations as behavioral complex situations; so, the respondents must understand the described behavior and evaluate its impact as resulting from the situation, perceived as a unit. This highlights, once more, the synergy between qualitative and quantitative methods, showing that every number tells a qualitative story Bancaleiro (2006).

The questionnaire was subjected to Cronbach's alpha procedure, to evaluate its reliability. As seen in Table 2, the instrument has good reliability (0.86), so it can support statistical analysis and interpretations related to the measurements obtained, who had no difficulty in understanding its questions. The questionnaire was also subjected to Cronbach's alpha procedure, to evaluate its reliability. As seen in Table 2, the instrument has good reliability (0.86), so it can support statistical analysis and interpretations related to the measurements obtained.

Table 2 Cronbach's Alpha from P-I questionnaire

	N	Cronbach's Alpha
Cases	225	0.861

Source: authors

4.2.2. The sample

The sample was composed of 225 university students and teachers and collected between September and November 2019.

Sample structure: 153 students, from the third year of Management, Economy, Sociology and Political Science courses; 72 teachers of the referred courses.

Male respondents: 149; female respondents: 76; no other gender signaled

4.2.3. The results

Table 3 shows that the variables - use of power and use of information - have a strong negative correlation. It is a first confirmation of the stated hypothesis..

Table 3 Correlation between the use of power and the use of information

		Power used	Managed information
Power used	Pearson correlation	1	-.857**
	Sig. (2-tailed)		.000
	N	225	225
Managed information	Pearson correlation	- .857**	1
	Sig. (2-tailed)	.000	
	N	225	225

** Correlation significant at 0,01 level (2-tailed)

Source: *authors*

Table 4 Impact of different levels of power on the use of information, by gender

Power behavior used in situations	Information utilized (mean)		Difference between means
	Women	Men	
Situation 1 *(extreme power used)*	1.4643	2.3889	0.9246
Situation 2 *(much power used)*	2.2957	2.7389	0.4432
Situation 3 *(a lot of power used)*	2.8414	3.3206	0.4792
Situation 4 *(medium power used)*	2.8414	3.3206	0.1356
Situation 5 *(Little power used)*	5.6033	5.7389	0.2075
Situation 6 *(Almost no power used)*	7.6986	7.4911	1.0676

Source: *authors*

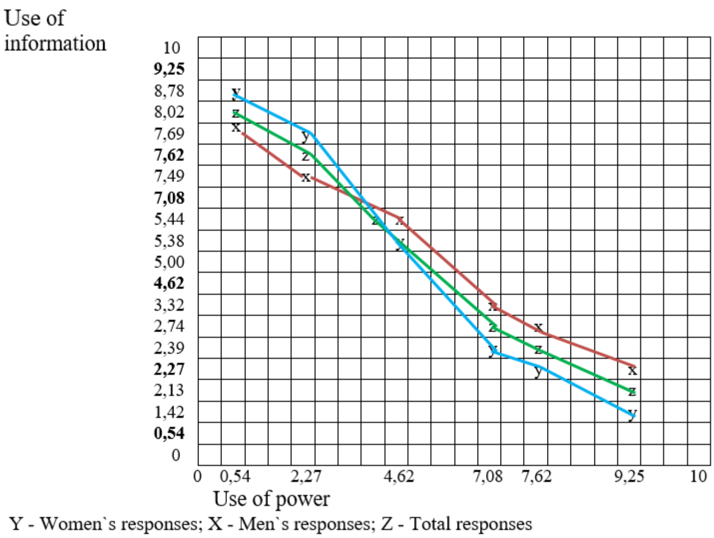

Fig. 4 Use of power and utilization of information in group data analysis and problem solving
Source: authors

When the use of power is great (extremely; a lot) the inhibition of the use of information is stronger in them; conversely, when power is little or very little used, the positive effect on the use of information is more evident in women than in men. As power has an impact on people through emotions, which are the energetic basis of human motivators (Pestana, Parreira and Moutinho, 2020), this difference may have a psychological explanation, the natural stereotype that emotions are stringer in women; however, the differences are not statistically significant.

However, the results are interesting in two ways:

- they confirm H1, showing that people perceive the negative impact of power attitude and tactics on the effective use of information in problem analysis and solving;
- they offer guidelines for the practice of leadership in problem solving and creativity groups. If a leader wants to make good use of the group's knowledge (large or small), he must reduce the use of power practices: these lower the level of truth in interactions; decrease the number of initiatives to inform the leader and

the group; distort the perception of the real; reduce the objectivity and relevance of the information provided. To do so, it is crucial to prepare the group to adopt predominant information-based practices; if it has a low level of knowledge and works essentially on an emotional basis, the leader must use more power to lead the group; but in that case, he must not forget that this behavior reduces group intelligence. As information is a more flexible and positive tool than power, the model advises to adopt a participative leadership, as much as the situations allow it (Parreira, Pestana and Oliveira, 2018).

If a leader wants to make good use of the group's knowledge (large or small), he must reduce the use of power practices to adopt predominant information-based practices; if it has a low level of knowledge and works essentially on an emotional basis, the leader must use more power to lead the group; but in that case, he must not forget that this behavior reduces group intelligence. As the information instrument is more flexible and positive than the power instrument, the model advises to adopt a participative leadership, as much as the situations allow it (Parreira, Pestana and Oliveira, 2018).

4.2.4. An example of problem analysis, guided by the ACSIP Model

We can now advance to the second part of this section and present an example of analysis and decision on a complex problem, guided by the ACSIP Model.

Problem: *To reduce inequality within (and between) nations (SDG 9 of the UN 20/30 agenda, 2017)*

This problem was chosen for its connection with other problems (poverty, education, health, as the UN text states itself) and the transformation of the world economic model, now discussed by scientific and academic groups involved with the so called “Pope Francisco’s Economy”, but also by political leaders, moved by the COVID-19 pandemic crisis and the climate threats.

The example is focused in the inequality within nations which is sufficient to highlight the modus operandi of the ACSIP Model, will follow an identical path in the analysis of other complex problems.

First step:

1. Define the physical boundaries of the system
Locate the problem in the system

Define with extent and precision the system and its physical boundaries.

Example: State of Brazil, Rio de Janeiro (RJ),

Questions: - Is the geographic and geological situation (oil exploration and related economic processes, for example) a negative or positive factor to the inequality phenomenon?

- How do the economic, sociocultural, political features of the State impact the observed inequality (including migrants from other States)?
- How are the relations with different entities of the context a positive factor to the inequality phenomenon?

2. Indicators for this analysis: traditional and current cultural practices; educational indicators; socioeconomic indicators; urban indicators; data on population movements and attitudes.

3. Assess how the system characteristics affect the complexity of the problem.
Result: The problem is located and the variables to analyse are identified.

Second step - Determine the informational complexity of the problem

1. The informational complexity of the inequality problem ($Cinf(S,P)$) includes its different dimensions, focused on the Model's interdisciplinary approach.
   Sociology, with a focus on social diversity and the drivers of inequality;
   Psychology, focused on the individual and patterns of interaction;
   Economy, focusing on income and employment issues;
   Medical sciences, focused on health-related issues;
   Urbanism and Architecture, with a focus on housing conditions, the quality of surroundings and mobility;
   *Political Science***,** applied to the study of individual rights and citizenship conditions.

Third step - Determine and ensure the level of required knowledge

1. Ensure the appropriate level of knowledge: is it sufficiently complex (in each discipline involved) for a comprehensive analysis and an effective solution to the problem?
   In SDG9, the complexity of the problem appears to be very high, in each discipline; therefore, the available level for the analysis and construction of solutions must be at the doctoral level, to fully understand the issues and to elaborate effective and encompassing solutions.
2. Ensure an analysis team with at least one doctorate in each discipline involved.
3. Check whether the work team shows effective open mind, listens to every argument, values information - even divergent, avoids rigid or authoritative positions in the problem discussion and analysis, demonstrating that team operates $NCa \geq Cinf(S,P)$.
4. Ensure that the methodologies and technical instruments used are based on the criteria of the required interdisciplinarity and are adequate to the required cognitive level: interview; questionnaire; impersonal and participant observation methods; urban and architectural methods of analysis; methods and criteria of economic analysis; interpretation of data based on an interdisciplinary view.

Fourth step - Ensure that the methodologies and technical instruments used are based on the criteria of the required interdisciplinarity

1. Check the use of the dialogical operator in the analysis of all the variables: variables interact; how much synergy is seen in the results; what contradictions are visible; where interdependencies manifest themselves.
   Example: interactions between inequality and: poverty, education, housing, exclusion, inequality; and between each one with the others.
2. Check the use of the recursive operator in the analysis of causal relationships and their effects in the set of identified variables.
   To what extent can causal relationships be checked and controlled in the set of identified variables.
3. Verify the use of the holographic operator in the interpretation of the data and proposed solutions.
   To what extent is it possible to have an integrated view of the problem? How do the components build the whole and how it maintains each component's identity?
   Example: establishing a general framework of indicators and drivers of inequality, combining effects of social, cultural and gender barriers; measuring socioeconomic competition intensity, poverty level, housing conditions and personal history.
   Result - A *unitas multiplex* portrait of the problem is accomplished, as the Model recommends.

Fifth step – Establish a flexible and adaptive action plan

The knowledge obtained is a solid basis for triggering factors to reduce inequality, assessing their impact multidimensionally, following the ACSIP Model requirements, namely the process of informed negotiation7, recommended in point 3 of the third step.

Result - That will most probably ensure the control over internal and external effects of the decisions made and lead to solutions free of perverse effects

5. AN OPEN CONCLUSION

As an open conclusion, we underline the goal of this article: to highlight the impact of the complex reasoning paradigm, and transfer it to the social and behavioral research practices, as Lannes (2014) recommends. The results enhance the importance of the work of the authors which were considered the basis of this way of thinking: Gödel's foundational work; Prigogine's explorations about the end of certainties, dissipative structures and bifurcations; Morin, with his epistemological scheme of complex qualitative and quantitative reasoning.

The flexibility of complex thinking allows us to adjust the model to a wide variety of problems, including complexity of real problems, where the data are certainly much more entangled than those shown in the chosen example, requiring undoubtedly more powerful tools, with a longer, heavier and more complicated process. But the level of complexity was sufficiently highlighted: a multi-level interdisciplinary analysis, to capture the complexity of the problem and ensure a more informed decision-making, at a higher conceptual level, therefore less likely to generate perverse effects.

Focused on these results, the authors are willing to continue this study, convinced that the complex reasoning paradigm is a promising tool to face the challenges resulting from the expansion of new technological systems into all fields of human life.

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PARADIGMA KOMPLEKSNOSTI: JEDAN MODEL ANALIZE SOCIJALNIH SISTEMA I PROBLEMA

Ovaj rad predlaže paradigmu kompleksnosti kao inovativno rasuđivanje za analizu problema u bihevijoralnim naukama. Počinje objašnjavanjem doprinosa najvažnijih autora koji su se bavili kompleksnom paradigmom rasuđivanja: Gedela, Prigožina i Morina. Oni nude osnovu za model analize i procene kompleksnih sistema i problema (ACSIP Model). Objašnjena su četiri postulata Modela i naglašena glavna hipoteza Modela - nivo kognitivnih operacija je najvažniji faktor kompleksnosti Sistema; da bi ga razumeli, kognitivni nivo analize mora da bude najmanje jednak nivou Sistema ili problema koji se analizira. U drugom delu rada, ilustrativna primena ACSIP Modela se primenjuje na analizu SDG 9 iz UN agende 20/30, pokazujući analizu kompleksnog problema koju vodi model kompleksnog rasuđivanja. Nakon toga, predstavljeno je empirijsko istraživanje da bi se verifikovala hipoteza četvrtog postulata modela. Rezultati potvrđuju hipotezu: korišćenje informacija od strane grupe je obrnuto proporcionalno korišćenju autoriteta (moći). Ovi rezultati nas navode da zaključimo da je paradigma kompleksnog rasuđivanja obećavajuće alatka za dobijanje sinergijskih rezultata u naučnoj analizi i rešavanju konkretnih socijalnih problema i da se suočimo sa kompleksnim izazovima koje donose sistemi veštaačke inteligencije.

Ključne reči: *Morinovi operateri; kognitivna kompleksnost; ACSIP Model; Socioekonomske nejednakosti, Sinergija rezultata*

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Review Paper

THE POSSIBILITY OF USING DISTRIBUTED LEDGER TECHNOLOGIES AS PAYMENT INFRASTRUCTURE

UDC 004.738.5

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Abstract. *The Internet of Things represents a communication network that enables people to interact with things, machines and objects in the business and living environment. Adding the ability to perform transactions to the information component leads to the creation of the so-called Internet of Value. Modern payment processing mechanisms do not meet the needs of the Internet of Value. In order to achieve a fast and economical financial flow, it is necessary to overcome the fragmentation of traditional payment systems and adopt the organizational structure of the Internet. The subject of the paper is the characteristics of three distributed ledger technologies. The aim of this paper is to determine the possibility of their use in order to build a payment infrastructure for the realization of the Internet of Value concept. Although the issue of security of the new payment infrastructure is equally important, the paper will focus on three key performances of the observed distributed ledger technologies: costs, throughput and scalability. The qualitative analysis shows that none of the analyzed technologies in practice has adequate performance in terms of throughput and scalability. Most operational solutions, even in experimental conditions, achieve poorer results than theoretically predicted ones.*

Key words: *Internet of Value, Blockchain, Hashgraph, Tangle, distributed ledger technologies, Internet of Things, Financial-technological integration*

JEL Classification: L17, O33

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INTRODUCTION

The beginning of the 21st century was marked by the race of manufacturers to raise the clock speed of computer processors and graphics cards and increase the Internet throughput. With the achievement of values that enabled the transfer of large amounts of data and its timely processing in application programs, the research focused on networking as many devices and learning given behaviors (Tomić, 2020, p. 363). The new information revolution relies on three processes: the Internet of Things, the processing of large amounts of data, and machine learning. The Internet of Things means a communication network that enables people to interact with things, machines and objects in the business and living environment (Tomić & Todorović, 2017, p. 97). In order to be involved in communication, devices must be equipped with appropriate sensors and microprocessors for receiving and processing basic information, actuators used to take certain actions, a modem for connecting to the Internet and software, which should enable data processing and, if possible, behavioral learning (Gupta & Gupta, 2020, p. 9). In this way, the Internet of Things represents the starting point of the information revolution, which provides inputs for processing large amounts of data and increases the need for machine learning.

A large number of established connections and communications do not have to refer only to the distribution of information, but can also imply the execution of payment transactions. The Internet of Things would thus become the basis for decentralized initiation and execution of transactions. Adding a financial component to the information would lead to the creation of the so-called Internet of Value (Floros, 2019). The biggest obstacle to the operationalization of this concept is the rigidity of traditional payment operations.

In order to fully use the potentials of the Internet of Things, it is necessary to build an adequate payment system. It should be borne in mind that the payment system would have to allow relatively fast finality of a large number of transactions, which would often belong to the category of micropayments. That is why the security and efficiency of the system are two key issues when designing a payment infrastructure for the Internet of Things. The subject of the paper will be the functional characteristics of three distributed ledger technologies (DLTSs). The aim of this paper is to determine the possibility of their use in order to build a payment infrastructure for the realization of the concept of the Internet of Value.

The paper consists of three parts. The first part will explain the concept of the Internet of Value, identify its potentials for changing the way of doing business and life and determine the conditions for its implementation. In the second part of the paper, the technical characteristics of all three technologies will be analyzed individually: Blockchain, Tangle and Hashgraph. A qualitative analysis against three criteria: costs, throughput and scalability, will be in the focus of the third part. A conclusion regarding the possibilities of using DLTs for the construction of a new payment infrastructure will be made upon comparing their performances against desired values of these criteria.

1. FINANCIAL-TECHNOLOGICAL INTEGRATION WITH THE AIM OF CREATING THE INTERNET OF VALUE

The Internet of Things represents a paradigm of information integration, in which devices and objects, which are passive in nature, become intelligent stakeholders, capable of collecting and distributing information (Tiwary et al., 2018, p. 23). Information sharing is not focused only on the people involved in certain processes, but the communication takes place on a m2m (man-to-machine or machine-to-machine) route. Intelligent objects not only process information, but also have the ability to take certain action, in terms of giving answers or sending requests. Given their ability to receive, process and transmit information, devices connected to the Internet of Things create a “smart work environment” or “smart home”. The end result of integrating devices into the Internet of Things should be the automation of routine activities in which the key source of error is the human factor. DeNisco (2017) lists manufacturing, transportation, medicine, power management, and consumer electronics as the five primary areas of application of the Internet of Things.

Basically, the Internet of Things does not require the implementation of payment solutions. The messages sent by the mentioned stakeholders do not have to be only of an informative nature, but they can initiate an action that involves making payment. This would give the devices, with the prior authorization of the owner, the opportunity to make purchases of the necessary products and services. Internet of Values is the key to permanent supply chains, whether they are households or industrial systems. Smart home appliances would be able to order new stocks of consumer goods on time, the condition of which they can monitor. Smart industrial systems would provide an additional tool for managing just-in-time supply chains, removing the human factor as the cause of temporary downtime in the production cycle. In a broader context, the Internet of Value refers not only to enabling devices to perform a transaction, but to networking all stakeholders into a global value exchange network. Money transfer would be only one aspect of the exchange, because the same infrastructure could be used to exchange financial instruments and for smart contracts (Finance monthly, 2018). In addition to the unique infrastructure, the key advantage of the Internet of Value should be the elimination of middleman and the reduction of exchange costs to a level close to zero (Ripple, 2017).

Modern payment organization does not meet the needs of the Internet of Value. Due to its manual nature, cash payments are not considered. Non-cash payment system shows good throughput characteristics, which means that it is able to support the growing volume of transactions. However, the key drawback in this case is the cost of transactions and the issue of creating a digital identity of devices as payment initiators. Due to the large number of middlemen (which, depending on the situation, may involve two to four institutions), non-cash payment transactions produce certain costs, which are charged in the form of a commission. That is why such a way of organizing is inadequate for micropayments. In order to achieve a fast and economical financial flow, it is necessary to overcome the fragmentation of traditional payment systems and adopt the organizational structure of the Internet. In other words, a payment system that would support the creation of the Internet of Value must enable the integration of traditional payment transactions, electronic payment systems such as digital wallets, electronic money and cryptocurrencies, through the construction of a completely new infrastructure (Cheng, 2015). Existing payment instruments could be replaced by completely new ones within this new infrastructure. The construction of a new payment infrastructure would redefine the number and role of middlemen in transactions, which would enable not only faster payment, but also lower costs.

There is an immanent security problem for all electronic payment systems. Therefore, ensuring the security of the new payment infrastructure would be one of the key issues. In addition, the new infrastructure must have satisfactory operational characteristics. In order to achieve the aim of the paper, the authors have formed a research question: do existing distributed ledger technologies have satisfactory operational characteristics? The analysis will include in particular cost, throughput and scalability. In the third part of the paper, a qualitative analysis will be performed in order to obtain the answer. A positive answer would mean that some or all of them can be used as the technological basis of the payment system for the Internet of Value. In case of a negative answer, the authors will explain their key operational shortcomings.

2. DISTRIBUTED LEDGER TECHNOLOGIES

Distributed ledger technologies are considered to be one of the foundations of the fourth industrial revolution. The concept became known to the general public with the advent of Bitcoin, the first cryptocurrency (Nakamoto, 2008). Although Blockchain, as the best-known form of this technology, is often equated with cryptocurrency systems themselves, DLTs are widely used in supply chain management, transportation, healthcare, and other industries. The basis of this technology is the general ledger, which records transactions between two parties, so that once entered ledgers cannot be subsequently changed (Iansiti & Lakhani, 2017). Transactions are any instruction that lead to a change in the state of the system and do not have to refer only to payments. DLTs are digitally stored data with consensus-based accuracy, mutually synchronized and shared independently of national borders, platforms used for its reading and writing, or institutions and organizations using it (Walport, 2015, p. 5). There is no single system administrator or central database in which data is entered first (Scardovi, 2016, п. 36).

In addition to Blockchain, Tangle and Hashgraph have been developed as alternative operational solutions to DLT. In the following parts, the key functional characteristics of all three technologies will be presented.

2.1. Blockchain

Blockchain is the first operational form of DLT. It is designed to operate in an environment where there is no central institution to validate data and where participants do not trust each other (Bamakan, Motavali & Bondarti, 2020). It consists of a series of blocks, in which the executed transactions are stored. The content of each subsequent block must be in accordance with the state to which the previously installed blocks have led. This means that entity X would not be able to spend in transaction q the funds it has already spent in previously accepted transaction p. If it tried, transaction q would be discarded and could not become part of the new block. The mechanism by which the authenticity of new transactions is verified and packed into blocks is called a consensus protocol (Schneider, 1990).

Figure 1 shows a general way of connecting blocks of information. The block has two parts: a header and a body. In the block header, enter the ordinal number, then the timestamp, to determine the chronological order of the assembled blocks, hash of the previous block, the Merkel tree root, which means that new transactions must be related to all previously entered, and hash of the new block. In the part that is marked as the body of the block, there are transactions that the miner wants to confirm.

The Blockchain is characterized by the division of roles among the participants. Nodes are participants that have permission to execute transactions, i.e. to appear as payers and recipients of funds. Miners are participants who pack transactions into blocks, validate them and add new blocks to the chain. The validation process itself involves reaching consensus among miners and can be more or less computer-intensive (Ismail & Materwala, 2019). The choice of consensus protocol depends on the type of Blockchain system used.

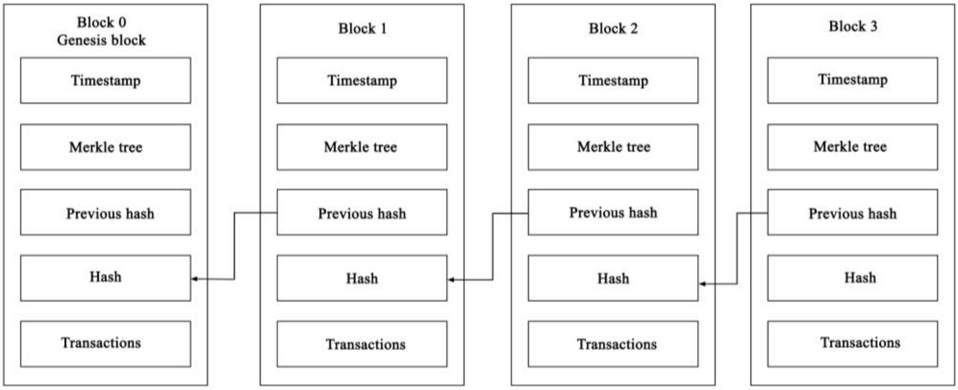

Fig. 1 Basic layout of connected blocks in a Blockchain
Source: Zhu, Zheng & Liv (2018)

The basic classification of Blockchain systems is into public and private. With public Blockchains, there is no strict division of roles, so one participant can only be a node or a miner if able to meet the criteria that are most often technical (Lin & Liao, 2017). With private Blockchains, there is a clear division of roles. A small number of pre-identified participants, who often form a consortium related to a business process regulated by a Blockchain, may play the role of a miner (Wang et al., 2019). Depending on the design of the system, the role of nodes can either be publicly available, or obtained under certain criteria. Private Blockchain systems are intended for business applications with a finite number of participants, which are often known in advance. To create a payment infrastructure, it is necessary that the role of nodes be publicly available to all interested participants, while the role of miners can be reserved for known participants.

Blockchain is already used in the construction of the payment infrastructure of a large number of cryptocurrencies. It has long been believed that cryptocurrencies will become not only decentralized electronic money, free of political influence, but also a means of micropayments, inherent in the Internet of Things. However, the reality is that cryptocurrencies are currently applicable as instruments of speculative investment. One of the reasons is the frequent and sudden change in the price of leading cryptocurrencies. Another reason is the performance of the consensus protocol.

All protocols intended for public Blockchain systems have problems with scalability, although there are marked differences in this group (Tomić, Todorović & Jakšić, 2021). Furthermore, miners in all protocols of this group must bear relatively high financial investments (with significant differences in terms of the amount of investment). As a result, all protocols imply the existence of some form of financial reward for assembling the block, which makes the system expensive and unsuitable for micropayments. The problem of protocols intended for private Blockchain systems is insufficient application in the field of cryptocurrencies. Theoretically, this group of protocols shows higher scalability and lower cost of the system itself (Tomić, 2021). Examples on which that can be determined are not representative, due to the very low use of cryptocurrencies based on them. In practice, the most widely used protocol is known as proof-of-work (PoW). It is at the same time the most unfavorable protocol in terms of performance, due to high initial investments, high energy load of the system and poor scalability.

2.2. Tangle

The first noticeable difference between Tangle and Blockchain is that transactions are not packed in blocks, but are entered independently in the public ledger. Although both Blockchain and Tangle rely on the mathematical concept of directed acyclic graph (DAG), Blockchain has only one path (from the previous to the next block), while Tangle represents a more complex network, in which transactions are not linearly related to each other, but involve branching. When entering each new transaction, the two previously entered ones must be validated so the initiator guarantees that they do not lead to double spending (Makhdoom et al. 2019, p. 259). In this way, Tangle technology brings the validation of transactions closer. All participants in the network are equal, without division of roles into initiators and miners (Safraz et al. 2019, p. 361). The appearance of a hypothetical Tangle network can be seen in Figure 2.

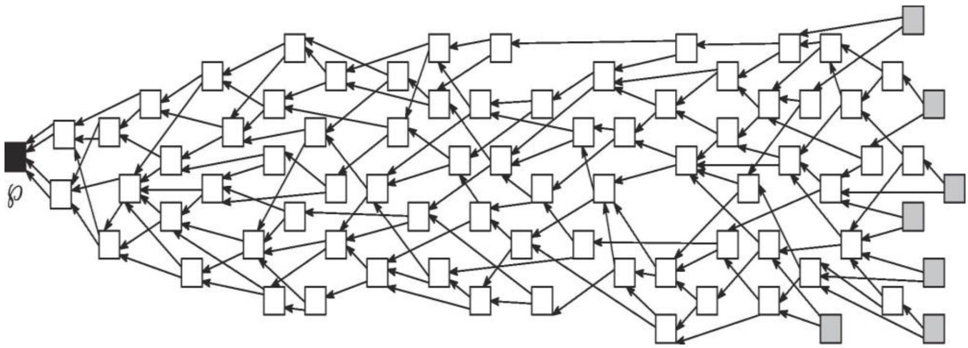

Fig. 2 Hypothetical appearance of a Tangle transaction network
Source: Popov, Saa & Finardi (2019, p. 162)

At the left end of the picture is the initial transaction, while the light squares mark all subsequent transactions that have been validated (in terminology they are marked as vertices). The directional arrows indicate which two transactions each new transaction selected as a reference when entering. Gray squares indicate new transactions that have been entered but have not yet been validated (in terminology, they are referred to as tips). The best outcome for the whole system would be that each initiator when entering a new transaction chooses tips for reference. However, in practice, the initiator does not know whether the transaction they take for reference has already been validated by other initiators. Therefore, Figure 2 shows that certain transactions are references for only the next one, while other references are for as many as the next four. In practice, Markov Chain Monte Carlo (MCMC) simulation is used to select reference transactions. After the selection, the initiator must check that the transactions do not represent a double spending of funds. They then perform an abbreviated form of the PoW algorithm, which is simpler than that applied to Bitcoin and other cryptocurrencies. It is necessary to find the appropriate nonce, whose hash fits with certain data in reference transactions (Popov, 2015, p. 3). Because it is simpler, PoW consumes less energy and lasts shorter than cryptocurrencies. After all this, the new transaction becomes part of the network, but remains a tip.

In order for a transaction to become a vertice, its "weight" needs to exceed the previously determined limit. The weight is proportional to the work invested in validating it. The total weight is the sum of the weight of the transaction itself and the weight of all transactions that directly or indirectly validate it (Silvano & Marcelino, 2020, p. 309). Thanks to MCMC simulation, those branches of the network that have a higher total weight are more likely to be selected to add new transactions, while the rest of the network is abandoned. In this way, the system is protected from the possibility of hiding certain transactions in a cut-off part of the network, which would enable double spending.

Tangle technology was designed as an infrastructure for IOTA cryptocurrency in 2015. As the name of the cryptocurrency itself suggests, its primary goal is to be used in the Internet of Things ecosystem. The absence of specialized miners allows the IOTA system to function without commissions, which makes it cheaper compared to competing cryptocurrency systems. The absence of commissions makes IOTA a good choice for micropayments, which will account for a significant share of total payments in the Internet of Things ecosystem (Jiang et al. 2019, p. 2). The biggest potential disadvantage of Tangle is considered to be the lack of implementation of smart contracts.

2.3. Hashgraph

Hashgraph is a variant of DAG, developed in 2016 by Swirld (Baird, 2016). The basic idea was to bring technology closer to the way people communicate and transmit information to each other. Nodes in Hashgraph often communicate, choosing a partner at random. During communication, they share information about new transactions initiated by them, but also about transactions initiated by other nodes. In that way, each node can check whether it is up to date with the latest events on the network, i.e. whether there is data on the last performed transactions. If it turns out that the node already knows everything it learns when communicating with the partner, it means that its information is equal to or better than the information of the partner. If it turns out that during the communication it received information about new transactions that it did not know, the node adjusts its database to new knowledge. The goal is for all nodes to be as well informed as possible thanks to frequent mutual communications (Sharma et al. 2020, str. 342-343).

The principle of information exchange is based on the same principle on which gossip is transmitted between people. During communication, the node tells the partner what it has done since the previous communication, but also what it has learned about other nodes during communication with them. That is why the way of determining the order and validity of transactions with a Hashgraph is called "gossip about gossip". A hypothetical network of Hashgraphs can be seen in Figure 3. Nodes are marked with A-E, while vertices denote events, which represent the process of information exchange. For example, Bob contacts Ed, where everyone exchanges information about known transactions. Dave and Carol do it at the same time. After that, Ed contacts Carol, conveys the information he had and the information he learned from Bob in the previous event. Carol contacts Bob at about the same time, passing on the information she had and the information she learned from Dave in the previous event. If there are no new transactions in the meantime, all four nodes – Bob, Carol, Dave and Ed –

have exactly the same information. In the next step, Bob contacts Alice, so she also gets all the information that Bob previously possessed.

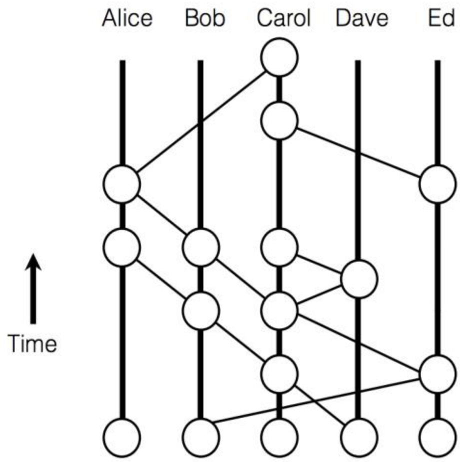

Fig. 3 Hypothetical appearance of a network of events in a Hashgraph
Source: Baird (2016)

The event consists of four components: a timestamp, which serves to establish a chronological order, transaction lists, hash of parents of the event, and transaction lists (Hassija, Saxena & Chamola, 2020, p. 54). The time of occurrence of the event is not the timestamp indicated by the initiator of the transaction, but the medial timestamp, which is determined based on the moment of receipt at all involved nodes. This prevents the initiator from falsifying the origin of the transaction and moving it chronologically earlier. Another consequence of this feature is that of the two transactions that occurred at the same time, the one about which gossip was distributed faster will be positioned chronologically earlier. Hash values represent the records of the last event for each of the included nodes.

Achieving consensus, i.e. validation of transactions, is done by the so-called virtual voting. Since all nodes have a copy of the same record of transactions, it can be assumed that each of them would declare to vote. Therefore, it is not necessary for the nodes to really vote, because based on the same information and the same sequence of events, they will always adopt the same list of transactions (Kaur & Gandhi, 2020, p. 393). Since the votes are not really sent, there is no burden on the network by sending messages, nor waiting for all nodes to declare themselves, so the decision is made immediately. The Hashgraph provides network security in accordance with the principle of asynchronous federated Byzantine agreement (aFBA), which leads to a positive outcome in the case when less than N/3 nodes are malicious, where N is the total number of nodes (Graczyk, 2018). Even in the event that malicious nodes virtually vote for the list of fraudulent transactions, in the following events, a fair majority will convince them that there is another list of true transactions.

3. Comparative Analysis of Distributed Ledger Technologies

The key operational performances of the payment systems are costs, throughput and scalability. In other words, the payment system must have an acceptable price of functioning, because the costs are passed on to the users of the system in the form of commissions. An ideal payment system would allow financial flow with costs close to zero. Then, the payment system must allow the flow of a large number of transactions per unit of time, thus demonstrating its applicability in global payments. Finally, the system must be scalable, i.e. its key characteristics (including throughput and cost) must not change drastically with the increase in the number of participants (Laudon & Traver, 2008). Systems that do not show good results according to the stated criteria can lead to a slowdown in the economic activity they need to service.

Blockchain is a pioneering endeavor in the field of DLT. Its qualities come to the fore when creating closed decentralized platforms, because it enables distributed input of new data and immutability of already entered ones (Schueffel, 2017). It is the dominant technical basis for creating cryptocurrencies. Despite that, Blockchain does not show good characteristics as a payment infrastructure. The main problems of PoW as the most common algorithm for reaching consensus are low throughput and low scalability. Low throughput leads to the accumulation of outstanding transactions, so payers have to offer more commissions for new transactions, in order to be built into the block across the line. Poor scalability is observed during a sharp increase in the number of miners who are actively working on assembling blocks. As the algorithm adapts to the total computing power, this means that as the number of miners increases, it will be relatively more difficult to find an appropriate solution to the cryptographic puzzle. Since the number of assembled blocks does not change, the reward that miners receive will not change either. This means that the entire system will operate at a loss, because the same reward will be shared with a larger number of miners, who consume more energy and invest more computing power. Both negative characteristics affect the increase in the price of an individual transaction.

The final conclusion is that Blockchain systems are as expensive as the technical infrastructure for the payment system of the future. Such a conclusion may seem contradictory at first glance, with the conclusion that almost all cryptocurrencies are based on them. It should be borne in mind that the most popular cryptocurrencies function as investment instruments and not as electronic money. Their value fluctuates too often with pronounced amplitudes, making them unsuitable for measuring the value of other goods (Ammous, 2018). Consequently, cryptocurrencies actually record many times fewer transactions than they would realize if actually used for payments. Despite this, most cryptocurrencies are already facing a backlog of transactions. The exception is Ripple, the cryptocurrency that uses the FBA protocol to reach consensus, which is intended for closed Blockchain systems. This protocol enables the execution of many times more transactions per second compared to the protocols for public Blockchain systems (Tomić, 2021). The company that issued Ripple is currently aiming to build a single payment system, which would enable the interoperability of the various payment systems that exist today. When it comes to the cryptocurrency itself, theoretically its throughput is up to 10,000 transactions per second, although the experiment yielded two and a half times lower value (McCaleb, 2017). The problem is that these values are not achieved in practice over a long period of time, as well as the high volatility of values.

Tangle currently represents the technical basis of a small number of cryptocurrencies, of which IOTA and Nano should be singled out. The advantage of Tangle is the reduction of transaction costs by eliminating the division of participants into nodes and miners. Also, it is possible to speed up the validation of executed transactions at the very moments when the system suffers the most pressure (Divya & Biradar, 2018). Therefore, the throughput of IOTA and Nano is higher than that of the most commonly used cryptocurrencies and can be compared to the values shown by Ripple. The advantage that these currencies have is that transactions are not packed in blocks, so the waiting time for validation of the transaction is shorter. While most systems suffer from the problem of scalability with the growth of the number of participants and executed processes, the situation is reversed with Tangle – the greater danger is the absence of participants and a small number of transactions, because it raises the time required to execute an individual transaction.

The main problem is that neither IOTA nor Nano are in the group of large cryptocurrencies. This does not mean that they have not yet been tested at the level of workload they would suffer with the number of users who have Ether or Bitcoin. At the beginning of March 2021, Bitcoin had a market capitalization of over 930 billion US dollars, IOTA about 3.7 billion, and Nano only 0.7 billion US dollars (coinmarketcap.com). Low capitalization was accompanied by lower trading volume. Two conclusions can be drawn: first, IOTA and Nano did not have the opportunity to show real limitations in throughput and scalability, and second, as less attractive in trade, they were partially spared the attacks suffered by systems of more popular cryptocurrencies. Despite this fact, IOTA suffered a serious attack at the beginning of 2020, which stopped the operation of the system for several days (Osbnorne, 2020).

A major drawback in the case of the widespread use of Tangle-based cryptocurrencies may be the use of the PoW protocol when validating transactions. Regardless of the fact that the cryptographic puzzle is simpler than with the Blockchain, there is certainly a strain on the computer's processor and power consumption. Therefore, it can be concluded that transaction costs still exist, only they are expressed indirectly, through energy consumption, and not directly through commission (Fernandes, 2018).

Hashgraph in theory offers the highest throughput of the observed technologies (it is estimated that there could be hundreds of thousands of transactions per second). Another advantage is that the Hashgraph alone ensures that all transactions are viewed chronologically and executed in that order. Since the system is closed, Swirld's primary goal was not to create a new cryptocurrency, but to build dedicated business applications for customers. The Hedera Hashgraph is the first open platform based on that technology, which in 2019 issued the Hbar token. The market capitalization of one Hbar coin at the beginning of July 2021 was about 1.62 billion US dollars, with a price of about 0.18 dollars per coin. The small significance that the Hbar token has in the cryptocurrency ecosystem does not provide an opportunity to validate the theoretically predicted high throughput values in practice.

CONCLUSION

The use of DLT in the development of payment systems has two trends. The first shows that a dominant number of cryptocurrencies are being developed on the technological basis of Blockchain, with PoW as a consensus protocol. The vast majority of cryptocurrencies have a negligibly small application in payments, so the problems of low throughput and scalability do not interfere with their work. It can be said that all decentralized cryptocurrencies are used only as speculative investment instruments.

In contrast, there is a trend of gradual centralization in DLT-based payment systems. The first venture in this direction came from Ripple, which proposed the development of cryptocurrency, but also an inter-institutional payment system, in which cross-border payments would be made faster and cheaper with the use of cryptocurrency as a means of currency conversion. Technology giant Facebook announced in June 2019 the creation of a new centralized stablecoin, Libra, which should be supported by a large consortium of companies from various sectors. The COVID-19 pandemic slowed down the implementation of this system, but the project is still active. Hashgraph technology fits into this trend, and can be used to create a closed system in which payment institutions communicate with each other and harmonize transaction lists. However, due to the equalization of nodes and miners, the Tangle could not be the basis for the creation of a centralized system.

The paper provides sufficient evidence to answer the formulated research question. None of the analyzed technologies has shown in practice that it has adequate performance in terms of throughput and scalability. Most operational solutions have shown that even in experimental conditions they achieve poorer results than theoretically predicted ones. In addition, almost all operational solutions are burdened with high costs, whether they are expressed directly, through commissions, or burden users indirectly, through electricity costs. Most systems have suffered a number of serious attacks in the past that have resulted in financial losses for some participants. Although security was not the criterion of analysis, the fact that in order to achieve adequate security, the payment system of the Internet of Value should be centralized cannot be ignored.

Payment operations have always functioned on the principle of centralization. In this regard, the demand for complete repression of middlemen from the new payment infrastructure is not realistic. The paper can contribute by providing key guidelines for building new systems and modifying existing ones in order to transform payment transactions. The Internet-of-Value-based payment system may require high throughput and low costs, but it can by no means be fully open and decentralized. The paper shows that the elimination of middlemen does not necessarily lead to a reduction in transaction costs, but opens up greater opportunities for abuse.

The key limitation of the paper is the lack of security analysis of these technologies. Although it is stated that the systems based on them suffered attacks from third parties, there was no analysis of the built-in protection mechanisms. It should be borne in mind that it is not possible to ensure the security of a system that does not bring costs, but it is only a question of how the costs will be distributed. If decentralized systems are insisted upon, consensus protocols will create lower or higher costs for participants. If security is entrusted to a centralized institution, or a consortium of a smaller number of participants, other users will have to pay for that security through commissions.

Subsequent research on this topic should be conducted periodically, in line with the progress of technological advances. Only Blockchain has been more than a decade old at the time of writing, while the other two technologies are still so new that they have not been adequately tested in practice. Within a few years, modifications may occur, which would bring some of the observed technologies closer to the possibility of being the technological basis of the payment infrastructure of the Internet of Value. At the same time, the number of networked devices in the Internet of Things will increase, which may change the perspective of looking at the problem of integration with the payment system.

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MOGUĆNOST KORIŠĆENJA DISTRIBUTIVNIH LEDGER TEHNOLOGIJA KAO INFRASTRUKTURE PLAĆANJA

Internet stvari označava komunikacionu mrežu koja omogućava interakciju ljudi sa predmetima, mašinama i objektima iz poslovnog i životnog okruženja. Dodavanje mogućnosti izvođenja transakcija informacionoj komponenti, vodi stvaranju tzv. interneta vrednosti. Savremena organizacija platnog prometa nikako ne odgovara potrebama interneta vrednosti. Da bi se postigao brz i ekonomičan protok finansijskih sredstava, potrebno je prevazići fragmentiranost tradicionalnih platnih sistema i usvojiti organizacionu strukturu interneta. Predmet rada su karakteristike tri tehnologije za decentralizovano upravljanje bazama podataka. Cilj rada je da se utvrdi mogućnost njihove upotrebe u cilju izgradnje platne infrastrukture za realizaciju koncepta interneta vrednosti. Iako je pitanje sigurnosti nove platne infrastrukture podjednako značajno, rad će biti fokusiran samo na performanse posmatranih tehnologija za decentralizovano upravljanje bazama podataka. Analiza je pokazala da ni jedna od analiziranih *tehnologija u praksi ne poseduje adekvatne performanse u pogledu propusne moći i skalabilnosti. Većina operativnih rešenja čak i u eksperimentalnim uslovima postižu slabije rezultate od teorijski predviđenih vrednosti.*

Ključne reči: *internet vrednosti, blokčejn, hešgraf, tengl, distribuirano upravljanje bazama podataka, internet stvari, finansijsko-tehnološka integracija*

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Original Scientific Paper

THE DRIVERS OF PRIVATE SECTOR INVESTMENT IN BOTSWANA: AN EXPLORATORY REVIEW

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Abstract. *This paper reviews the drivers of investment by the private sector in Botswana for the period from 1980 to 2018. The paper discusses the investment policies that the government has adopted over the years, the incentives, as well as the institutions that have been established to promote private sector investment. The Botswana government's economic development strategy is aimed at promoting economic growth through the private sector. Some of the key determinants of private investment, which have been analysed, include economic growth, public investment, credit to the private sector, gross domestic savings, trade openness, interest rate, inflation and foreign direct investment. Since the 1980s, the private sector investment has been fluctuating between 34.5 percent and 12.1 percent, with the highest level being recorded in 1980 and the lowest in 1996. The study shows that economic growth averaged 6.4 percent, public investment was 10.3 percent, credit to the private sector was 18.3 percent, gross domestic savings was 35.9, trade openness was 101.4 percent, interest rate was 3.6 percent, inflation was 8.9 percent and lastly, foreign direct investment was 2.6 percent during the study period.*

Key words: *private sector investment, economic growth, determinants, policies, Botswana*

JEL Classification: E2

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1. INTRODUCTION

Economic growth is an important determinant of private investment. The linkage between economic growth and private investment has been studied by various researchers and their findings indicate a positive relationship between the two variables (see Karagoz, 2010; Adugna, 2013; and Nainggolan *et al.* 2015). The desired capital stock is determined by the cost of capital and the level of output (Serven & Solimano, 1992). Many studies in the literature have proposed the determinants of private investment. The determinants are public investment (Ribeiro and Teixeira, 2001; Bint-e-Ajaz & Ellahi, 2012); credit to the private sector ((Mitiku, 1996; Asante, 2000); trade-related variables such as trade openness, terms of trade and exchange rates (Acosta & Loza, 2005; Karagoz, 2010). Other variables include public debt; external debt; financial markets; credit markets; political instability; savings and financial development (see Acosta & Loza, 2005; Sisay, 2010; Lau *et al.*, 2019); and interest rates (see Bader & Malawi, 2010; Suhendra & Anwar, 2014; Magableh & Ajlouni, 2016).

The private sector has been identified by the government of Botswana as one of the key drivers of economic growth, diversification and employment creation and the government has come up with several policies and initiatives to promote the sector (Republic of Botswana, 2019). According to OECD (2005:112), "enforcing market discipline and promoting efficient allocation and use of economic resources, through the encouragement of private sector involvement in the country's economic development, has been one of the key aspects of public policy and public sector reform agenda in Botswana". Against this background, this study aims to analyse the trends of private investment and its determinants in Botswana during the period 1980 – 2018. The study further assesses the policies that have been pursued to promote private investment in Botswana during the study period.

The rest of the study is organised as follows: Section 2 reviews the government's investment policies, incentives to promote private investment, and the institutions established to promote private investment. Section 3 discusses the trends of private investment and section 4 reviews the macroeconomic drivers of private investment in Botswana. Section 5 concludes the study.

2. INVESTMENT POLICIES IN BOTSWANA

Since its independence in 1966, the Botswana government has been working on economic diversification and private sector development. The Republic of Botswana (2019) states that the new economic development strategy is to promote economic growth through the private sector. The economic growth of the country over the years has been due to the prolonged and rapid expansion of the mining sector and the government, which has been largely financed by the revenue from the mining sector (Bank of Botswana, 2000). As the government and the mining sector account for almost half of the country's gross domestic product (GDP), the country needs to diversify as it cannot depend on one sector of the economy (Bank of Botswana, 2000). Since the mineral sector lacks the potential for rapid economic growth, in order to boost diversification, the government needs to promote investment in other sectors of the economy and this was the objective of the National Development Plan (NDP) 7 and 8 (Kgakge, 2002). The efforts by the government have been working as there has been a decrease in the share of the mining sector and an increase of the non-mining sectors in the economy (Republic of Botswana, 2019). The contribution of the mining sector share to GDP declined from 25 percent in 2008 to 18 percent in 2018, while that of the non-mining sectors increased from 75 percent to 82 percent during the same period (Republic of Botswana, 2019:4)

The NDP 10, which was for the period April 2009 to March 2016, prioritised growth in the private sector. According to the Republic of Botswana (2009), the acceleration of the diversification of the economy from dependence on diamond towards the growth of the private sector was the plan of the NDP 10. For the NDP 10, the government had the strategy that seeks to "create a private-sector enabling and supportive policy environment, stimulate increased domestic and foreign private investment, and enhance competitiveness in goods and services markets" (Ministry of Finance and Development Planning, 2013:5). To develop a private-sector-friendly environment, the government aimed to improve the business climate by removing the negative effects of all the administrative, bureaucratic and regulatory barriers detrimental to private sector development (Republic of Botswana, 2009).

In the NDP 11, the first medium-term plan, which starts from March 2017 to March 2023 towards the implementation of the country's second vision – Vision 2036 is outlined (Republic of Botswana, 2017). The NDP 11 aims to eliminate poverty and create employment. According to the government of Botswana, this will be achieved through the "implementation of six national priorities, namely i) developing diversified sources of economic growth; ii) human capital development; iii) social development; iv) the sustainable use of national resources; v) consolidation of good governance and strengthening of national security; and vi) the implementation of an effective monitoring and evaluation system" (Republic of Botswana, 2017:XV). According to the NDP 11 the strategies to create employment opportunities and promote economic growth will be implemented by "developing diversified sources of economic growth through initiatives such as beneficiation; cluster development; special economic zones; an economic diversification drive; and local economic development" (Republic of Botswana, 2017:XV).

According to NDP 11, the Botswana government aims to maximize the value addition from minerals through mineral beneficiation in order to promote the development of the private sector and grow the economy (Republic of Botswana, 2017). The government will also aim to adopt a cluster-based agenda that focuses on sectors in which the economy has a comparative advantage, such as the diamond, beef, tourism, financial services and mining sectors, emerging education as well as health services sectors (Republic of Botswana, 2017:59). The programmes such as local economic development and the Private Sector Development Strategy (PSDS) will be used to implement this initiative (Republic of Botswana, 2017).

As part of cluster development, the NDP 11 aims to promote the special economic zones through tax and regulatory reforms that will enable them to create job opportunities and grow the economy (Republic of Botswana, 2017). This initiative will promote the domestic and foreign direct investment which will significantly contribute to economic growth and create job opportunities (Republic of Botswana, 2017). During the NDP 11, the achievements of the economic diversification drive strategy will be consolidated by implementing the new Industrial Development Policy (IDP) in order to achieve the government objective of diversified and sustainable industries and ensure the beneficiation of local raw materials (Republic of Botswana, 2017:60). The last initiative will be local economic development, which will ensure that the country creates an environment that will encourage local investment and promote both SMMEs and major industries in the economy and access to external markets, private investment and provision for infrastructure crucial for this initiative (Republic of Botswana, 2017).

Over the years, the Botswana government has implemented a number of schemes aimed at investment in private sector enterprises and parastatals. According to the Bank of Botswana (2001), some of the schemes implemented to finance private sector enterprises include the Financial Assistance Policy (FAP) and Small, Medium and Micro Enterprises (SMMEs).

The FAP was introduced in 1982 with the objective of facilitating the development of new and expanding productive enterprises in order to create employment opportunities and diversify the economy which is dependent on the mining sector (Valentine (1993). The objectives of the FAP were to facilitate rapid industrialisation; to diversify the economy away from dependence on large-scale mining and non-cattle and non-traditional agricultural projects; diversify the economy across regions, away from the major urban and peri-urban areas, and encourage rural industrialisation; to encourage sustained employment of unskilled labour and address Botswana's unemployment problem; to promote the acquisition and upgrading of the skills of Botswana citizens through training; and to stimulate citizen participation in the ownership of productive assets (Valentine, 1993:10).

The SMMEs policy, which is a financing programme, was introduced in 1999 (Bank of Botswana, 2000). The SMMEs policy aimed to achieve the following objectives, which are "to foster citizen entrepreneurship and empowerment; encourage the development of a competitive and sustainable SME community; achieve economic diversification; create sustainable employment opportunities; promote exports; promote the development of vertical integration and horizontal linkages in primary industries (agriculture, mining and tourism) for SMEs; and improve efficiency in the delivery of products to business." (OECD, 2005:113).

Due to the shortcomings of these schemes, both the FAP and SMMEs have been discontinued and replaced by the Citizen Entrepreneurial Development Agency (CEDA). The CEDA provides subsidised loans to commercially viable enterprises and runs a venture capital scheme (Bank of Botswana, 2001). The venture capital is made available for joint ventures between local and foreign investors (Bank of Botswana, 2001). The objectives of the CEDA are as follows: (i) to support business development through various funding mechanisms; (ii) to back agro-business, services property and manufacturing through subsidised loans, as well as to help citizens partner with foreigners in joint ventures; (iii) to foster citizen entrepreneurship and empowerment and promote economic diversification; (iv) to encourage the development of competitive and sustainable citizen enterprises; and (v) to create sustainable employment opportunities (Bank of Botswana, 2015:107).

One of the tax incentives to encourage investment is that companies registered with the International Financial Services Centre (IFSC), which has been replaced by the Botswana Investment and Trade Centre (BITC), benefit from zero-rated VAT and exemption from both Withholding Tax and Capital Gains Tax, while other companies pay 10 percent VAT, 7.5 percent Withholding Tax (reduced from 15 percent since 2011), and 15 percent Capital Gains Tax (OECD, 2014).

The government has also established institutions to promote investment, such as the Botswana Export Development and Investment Authority (BEDIA), which took over the work of the Trade Investment and Promotion Agency (TIPA) which is export development and investment promotion (Bank of Botswana, 2000). BEDIA's objective is to promote investment, especially in the manufacturing sector (Bank of Botswana (2000). It aims to achieve its objectives through the promotion of the country as an investment destination and to serve as a one-stop service centre that assists investors with permits for work and residence; securing of land and buildings; business licensing; and assist with identifying potential citizen joint venture partners (Bank of Botswana (2000:87).

Another institution is the Botswana Investment and Trade Centre (BITC) which, according to the OECD (2014), was launched in 2012 after the merger of BEDIA with the Brand Botswana Management Organisation (BBMO) and the International Financial Services Centre (IFSC). Its objectives include investment promotion and attraction, and export promotion and development and as a one-stop service centre for investors, it minimises regulatory and bureaucratic costs (Bank of Botswana, 2015). In addition, the BITC provides business facilitation services such as company and business registration, trade licence applications and entry visas, and work and residence permits (Bank of Botswana, 2015).

3. Private Investment Trends in Botswana

The Botswana government has created an enabling environment for the private sector in order to grow the economy. Private investments in Botswana have fluctuated since the 1980s and averaged 18.9 percent as a percentage of GDP for the period 1980 to 2018. The highest level of private investment being recorded was 34.5 percent in 1980 and the lowest was 12.1 percent in 1996. Private investment decreased from 34.52 percent in 1980 to 12.62 percent in 1986 before it increased to 23.77 percent in 1990. After 1990 it dropped and stayed below 15 percent for most of the 1990s. Investment by the private sector as a percentage of GDP declined from 23.77 percent in 1990 to 12.14 percent in 1996. In the period 1992 to 2009, the performance of the private sector was lower at an annual average of less than 20 percent. However, private sector investment as a percentage of GDP improved in 2010 when it rose to 20.53 percent. Figure 1 shows the trends of private investment in Botswana as a percentage of GDP from 1980 to 2018.

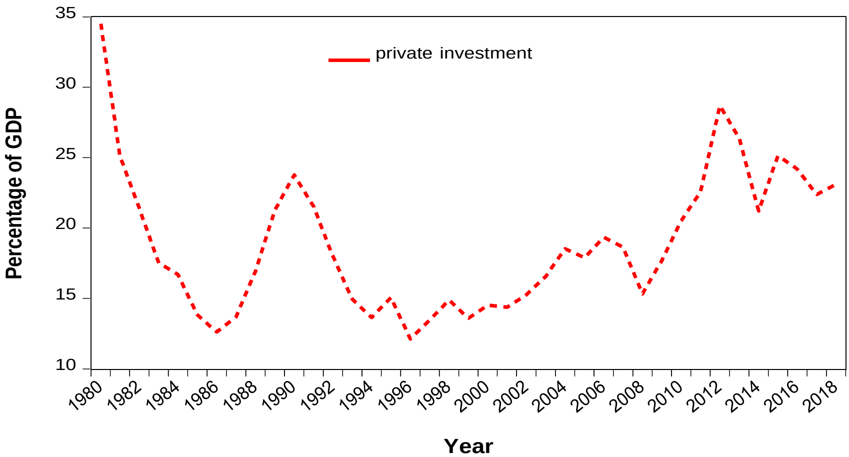

Fig. 1 Private Investment as a Percentage of GDP in Botswana (1980–2018)
Source: Own compilation from World Bank Development Indicators (2020).

Private investment increased from 14.39 percent in 2001 to 18.54 percent in 2004. In the 2003/04 period, total gross domestic investment accounted for 25.5 percent of GDP, compared with 24.5 percent in the 2002/03 period and the increase was due to growth in private investment (OECD, 2005). Private investment was on the decrease before the 2008 financial crisis that affected many economies. Private investment decreased from 18.63 percent in 2007 to 15.33 percent in 2008. From 2009 investment by the private sector was on the rise once more and reached 28.69 percent in 2012 before decreasing to 21.22 percent in 2014.

4. Trends of Macroeconomic Drivers of Private Investment in Botswana

Many macroeconomic variables have been identified in the literature as the determinants of private investment. They include economic growth, public investment credit to the private sector, inflation, gross savings, foreign direct investment, interest rate, and openness of the economy. These macroeconomic variables are discussed within the Botswana context in this section.

4.1. Economic Growth

The economic growth rate in Botswana fluctuated in the review period. For the period 1980 to 2018, private investment averaged 18.9 percent as a percentage of GDP whereas economic growth averaged only 6.4 percent in the same period. The highest growth rate was 19.5 percent in 1988 and the lowest in 2009 with a growth rate of –7.7 percent (see figure 2). Figure 2 presents economic growth rates and private investment as a percentage of GDP in Botswana from 1980 to 2018.

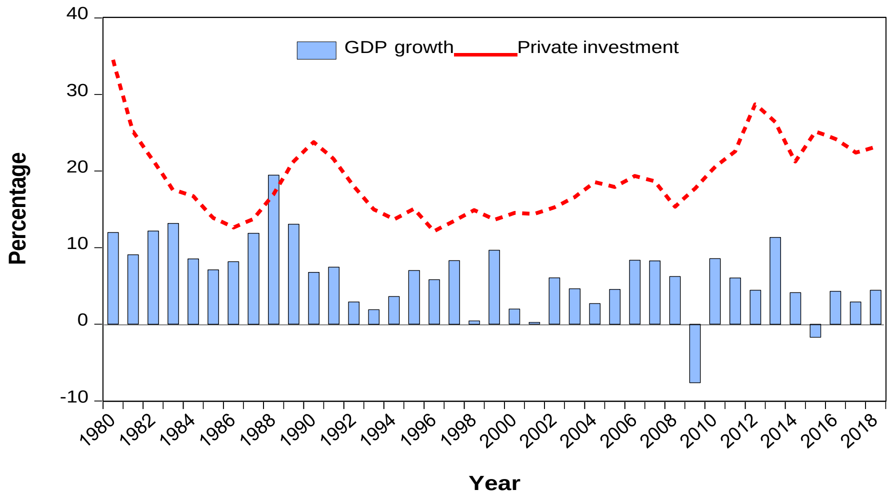

Fig. 2 GDP Growth Rate and Private Investment in Botswana (1980–2018)
Source: Own compilation from World Bank Development Indicators (2020)

The sharp decrease from 8.3 percent in 1997 to 0.4 percent in 1998 could have been because of the financial crisis that affected many economies. After 1998, the economy of Botswana grew to 9.7 percent in 1999 before it slowed down to 0.3 percent in 2001. The reason for higher growth in 1999 was increased activity in the mining sector and the

Orapa expansion project during the first half of 2000 (Bank of Botswana, 2000). In 2010 economic growth picked up and spiked to 8.6 percent. Afterwards, it decreased to –1.7 percent in 2015.

4.2. Public Investment

Public investment is a determinant of private investment as it can either crowd in or crowd out private investment (see Ghali, 1998). From 1980 to 2018, private investment in Botswana has always exceeded investment by the public sector. Botswana private investment as a percentage of GDP averaged 18.9 percent, while public investment as a percentage of GDP averaged 10.3 percent for the period 1980 to 2018. Figure 3 displays public and private investment as a percentage of GDP in Botswana from 1980 to 2018.

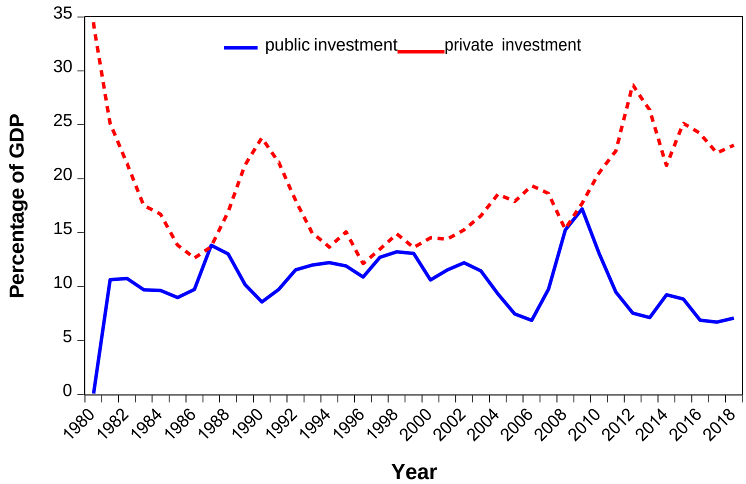

Fig. 3 Public Investment and Private Investment in Botswana (1980–2018)
Source: Own compilation from World Bank Development Indicators (2020)

While private investment declined continuously from 1990 to 1994, public investment continuously increased (see figure 3). Investment by the public sector strengthened from 8.6 percent in 1990 to 13.7 percent in 1994. According to the Bank of Botswana (2000), the share of gross fixed capital formation, which showed the increased pace of the government's investment programme, grew during the mid-1990s. But public investment as a percentage of GDP decreased from 13.2 percent in 1998 to 10.6 percent in 2000. The share of gross fixed capital formation declined in 1999/2000 owing to the slower real growth rates of government development spending (Bank of Botswana, 2000).

In 2003 public investment declined to 11.5 percent from 12.2 percent in 2002 and continued to diminish until 2006. In 2007, it rose to 9.8 percent and reached 17.2 percent in 2009 to decline again to 7.1 percent in 2013. For the period 2008 to 2009, both public and private investment averaged 15 percent in 2008 and 17 percent in 2009. Public investment was below 10 percent as a percentage of GDP from 2014 to 2018, whereas private investment as a percentage of GDP was above 20 percent.

4.3. Domestic Credit to the Private Sector

Credit is an important determinant of investment. For the period 1980 to 2018, private investment as a percentage of GDP averaged 18.9 whereas credit to the private sector as a percentage of GDP averaged 18.3 in the same period. As can be seen from figure 4, from 1980 to 1997, an upward and a downward trend in domestic credit to the private sector was evident in Botswana. It decreased from 11.3 percent in 1980 to 9.7 percent in 1997. However, from 1998 it started to grow, and from 2001 until 2018, it surpassed private investment levels.

Credit to the private sector increased from 22.7 percent in 2007 to 25.8 percent in 2008. It continued to rise to 28.9 percent in 2009 but dived to 27.2 percent in 2010. Unlike most other African countries, Botswana was able to provide finance for the SMEs through the two financial schemes, which are the Micro Credit Scheme and the Credit Guarantee Scheme that it established (OECD, 2005). The trend shows that when domestic credit decreases, private investment decreases, and when domestic credit increases, private investment also increases. The reason for this could be that the private sector needs credit from banks to finance its projects. Figure 4 presents domestic credit to the private sector and private investment as a percentage of GDP in Botswana from 1980 to 2018.

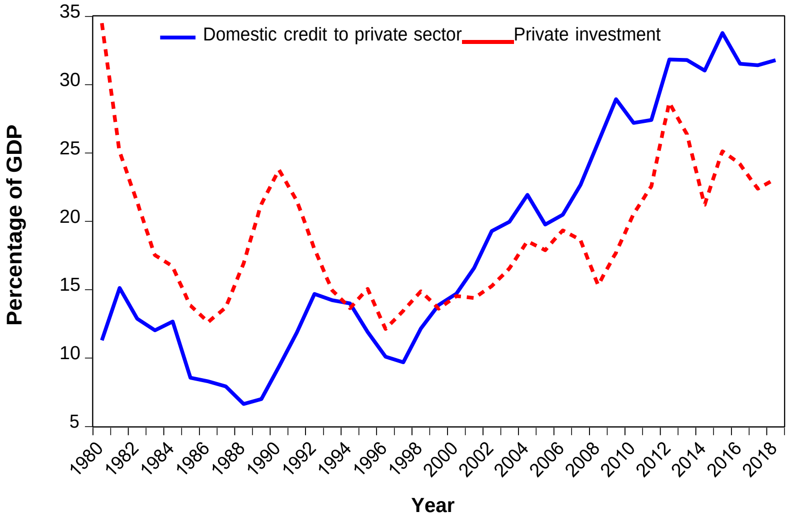

Fig. 4 Domestic Credit to Private Sector and Private Investment in Botswana (1980–2018)
Source: Own compilation from World Bank Development Indicators (2020)

4.4. Gross Domestic Savings

Domestic savings also boost investment, and according to Munir *et al.* (2010), private savings speed up private investment. Gross domestic savings for the period 1980 to 2018 averaged 35.9 percent as a percentage of GDP in Botswana. Figure 5 shows that from 1982 gross domestic savings were higher than private investment. The Botswana government is a major saver, and in June 1990, it accounted for over half of gross domestic savings, but this figure fell to just below 30 percent by June 1995 (Bank of Botswana, 2001). Figure 5 illustrates gross domestic savings and private investment as a percentage of GDP in Botswana from 1980 to 2018.

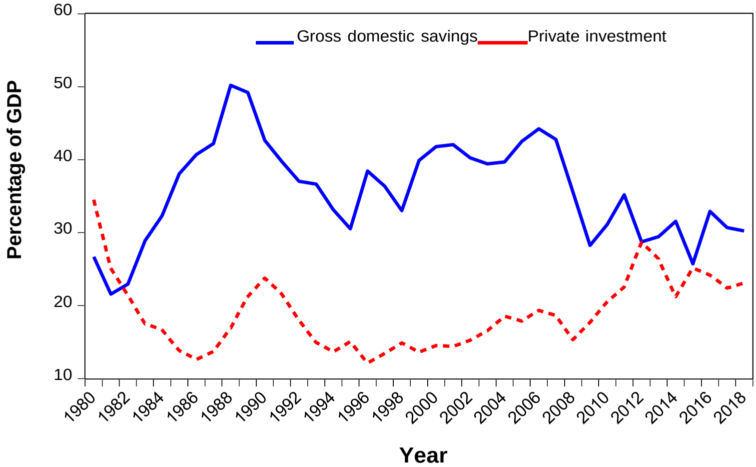

Fig. 5 Gross Domestic Savings and Private Investment in Botswana (1980–2018)
Source: Own compilation from World Bank Development Indicators (2020)

The Botswana government's savings performance depends largely on revenue from the mining sector (Bank of Botswana, 2001). It steadily rose from 1982 to 1988 and then continuously declined from 1988 to 1995. The performance of gross domestic savings in Botswana during the 1980s was characterised by an increasing trend but in the early 1990s by a declining trend (see figure 5). In the late 1980s, private investment intensified whereas in the early 1990s, it slumped. In 1996 gross domestic savings increased to 38.4 percent from 30.5 percent in 1995 before declining to 33 percent in 1998. Gross national savings decreased in 2002 to 40.3 percent from 42.1 percent in 2001. By 2004 it stood at 39.7 percent. According to the Bank of Botswana (2001), the decline in gross domestic savings during this period was due to a decrease in public savings. In 2009 gross savings stood at 28.2 percent compared to 35.6 percent in 2008 and 44.2 percent in 2006. After 2009 savings improved and rose to 35.2 percent in 2011.

4.5. Trade Openness

The openness of a country is vital, and according to Fielding (1997), an increase in trade has a positive impact on domestic investment. Trade openness is measured by the ratio of imports plus exports to the GDP. Botswana's ratio of imports plus exports to its GDP exceeded 70 percent for the period 1980 to 2018. For the period 1980 to 2018, private investment averaged 18.9 percent as a percentage of GDP, whereas trade openness averaged 101.4 percent as a percentage of GDP in the same period. The OECD (2005) affirms that exports in the country are limited to a small number of commodities (minerals) and focused at just a few destinations which are mostly in Europe. The country membership in the Southern African Customs Union (SACU) may have largely dictated its trade policy over the years because the agreement states that all trade negotiations or agreements between Botswana and third parties must be acceptable to other SACU members (OECD, 2005). Figure 6 shows trade openness and private investment as a percentage of Botswana's GDP from 1980 to 2018.

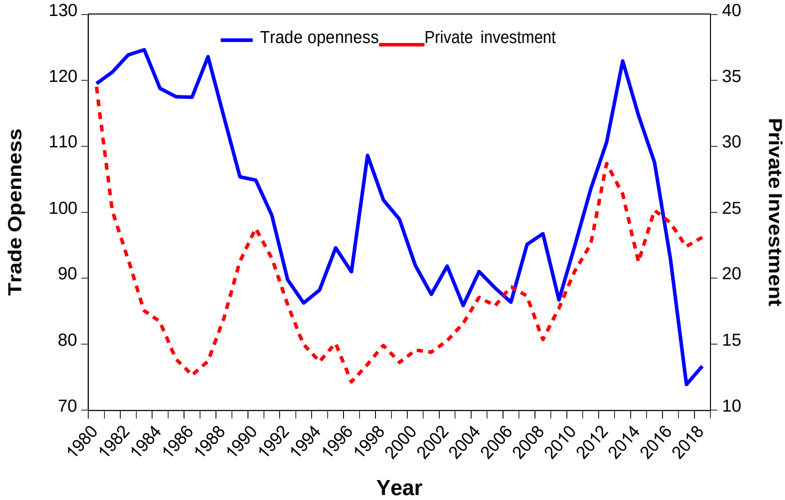

Fig. 6 Trade Openness and Private Investment in Botswana (1980–2018)
Source: Own compilation from World Bank Development Indicators (2020)

In the early 1980s, trade openness grew from 119.5 percent in 1980 to 124.6 percent in 1983. However, from the late 1980s to the early 1990s, there was a decline in trade openness measured by the ratio of imports plus exports to Botswana's GDP. The level of trade openness dropped from 123.6 percent in 1987 to 86.2 percent in 1993. In 1994 it started to rise and stood at 91 percent in 1995. The improvement in the country's trade openness during this period coincided with measures towards a more liberal trade regime (Malefane & Odhiambo, 2016). Trade openness improved to 108.6 percent in 1997 and, thereafter, continuously declined to 87.5 in 2001.

Trade openness in the 1990s and 2000s was less than in the 1980s. According to Malefane and Odhiambo (2016), the decline in Botswana's trade openness in the 1990s coincided with the agricultural sector's declining share in exports. Botswana's trade openness dropped from 96.7 in 2008 to 86.7 in 2009. The country's economy recovered after 2009, and trade openness increased from 86.7 percent in 2009 and to 123 percent in 2013. From 2013 to 2017, it continuously declined. Trade openness fell from 123 percent in 2013 to 73.9 percent in 2017. A factor that could have contributed to the slowdown was the decline in the export of rough diamonds in 2015 because of a decrease in the global market demand (Bank of Botswana, 2015).

4.6. Real Interest Rate

The real interest rate is a determinant of private investment. A study by Greene and Villanueva (1991) shows that there is a negative relationship between interest rates and private investment. For the period 1980 to 2018, private investment averaged 18.9 percent as a percentage of GDP, whereas real interest rate averaged 3.6 percent in the same period. The real interest rate of Botswana fluctuated from 1980 to 2018. In 1980, the interest rate was –1.6 percent, and in 2018 it reached 5.5 percent. Figure 7 presents the trends of real interest rate and private investment as a percentage of Botswana's GDP during the period 1980-2018.

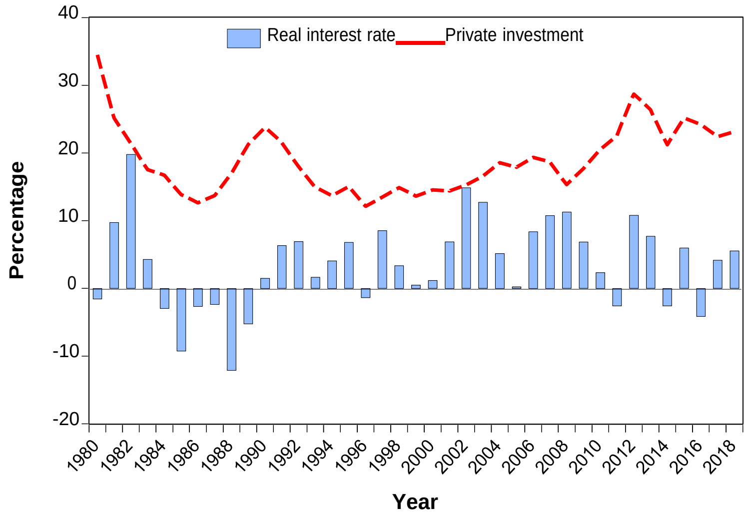

Fig. 7 Real Interest Rate and Private Investment in Botswana (1980–2018)
Source: Own compilation from World Bank Development Indicators (2020)

In 1980, the real interest rate was –1.6 percent. A sharp increase to 19.8 percent followed in 1982, the highest for the period 1980 to 2018. It declined sharply from 19.78 percent in 1982 to –9.3 in 1985. The trend shows that from 1984 to 1989, the real interest rate was negative. From 1989 it steadily grew to 6.9 percent in 1992 only to fluctuate again. In 1996, it was a negative rate of –1.4 percent before rising to 8.5 percent in 1997 and decreasing to 0.5 percent in 1999.

Botswana's real interest rate spiked to 14.8 percent in 2002 from 1.1 percent in 2000. It fell to 0.2 percent in 2005, then rose to 11.3 percent in 2008, and declined again to –2.6 percent in 2011. In 2012, there was a sharp increase from -2.6 percent in 2011 to 10.8 percent. The increase in the real interest rate in 2012 was owing to a decline in inflation (Bank of Botswana, 2012).

4.7. Inflation Rate

Inflation is also a determinant of private investment, and according to Hassan and Salim (2011), inflation erodes the purchasing power of money. During the period 1980-2018, private investment averaged 18.9 percent as a percentage of GDP, whereas inflation averaged only 8.9 percent in the same period.

Inflation was 13.6 percent in 1980 and 8.1 percent in 1985, the lowest for the 1980s. It then increased to 10 percent in 1986 before it sank to 8.4 percent in 1988. In 1992 the inflation rate grew to 16.2 percent, the highest annual inflation rate since 1981. After 1992, it continuously declined. It was 6.7 percent in 1998, increased to 8.6 percent in 2000, before it declined to 6.6 percent in 2001. It then rose to 9.2 percent in 2003. According to the Bank of Botswana (2000), a rise in fuel prices was one of the factors that drove inflation in 2000, which led to increased production costs. The decline in 2001 was the result of less external inflationary pressure, reinforced by the tight monetary policy maintained throughout the year (Bank of Botswana, 2001).

Figure 8 indicates the inflation rate and private investment as a percentage of Botswana's GDP from 1980 to 2018.

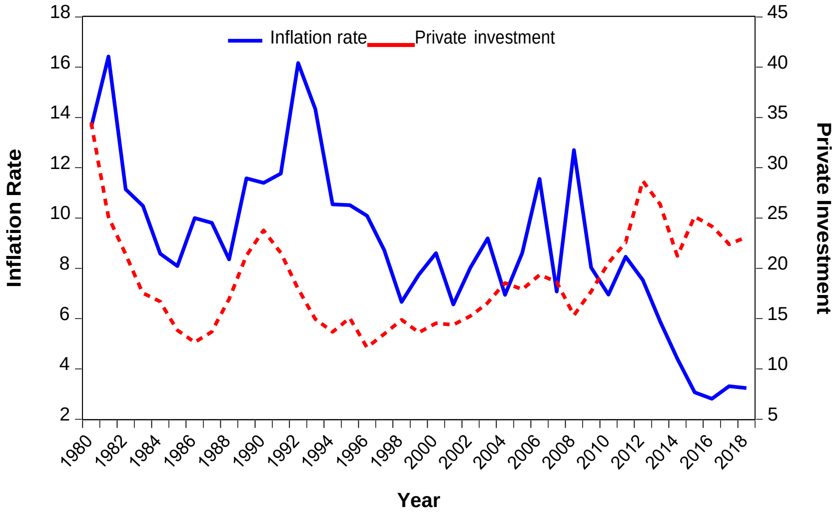

Fig. 8 Inflation Rate and Private Investment in Botswana (1980–2018)
Source: Own compilation from World Bank Development Indicators (2020)

Inflation declined from 11.6 percent in 2006 to 7.1 percent in 2007 before it increased to 12.7 percent in 2008. The high inflation in 2006 was due to the higher world prices of petroleum and the result of the new exchange rate regime that was introduced in May 2005 (Bank of Botswana, 2007). In 2007 the Monetary Policy Statement (MPS) set an annual inflation objective of 4 to 7 percent, but because of rising international oil prices and subsequent cost increases of imported foodstuff and petroleum products, the inflation rate was above 7 percent (Bank of Botswana, 2007). It maintained its downward trend from 12.7 percent in 2008 to 7 percent in 2010. The trend of the inflation rate shows that from 2013 until 2018, the inflation rate was within the target of 3 to 6 percent (see figure 8).

4.8. Foreign Direct Investment

Foreign direct investment is also a determinant of private investment. Foreign investment can stimulate domestic private investment, but it can also crowd out domestic private investment, as was found by Mutenyo *et al.* (2010). In Botswana, private investment has been higher than foreign direct investment for the period 1980 to 2018. For the period 1980 to 2018, private investment averaged 18.9 percent as a percentage of GDP, whereas foreign direct investment as a percentage of GDP averaged only 2.6 percent in the same period.

Foreign direct investment was higher in the 1980s than in the 1990s: it averaged 4.6 percent in the 1980s and just 0.3 percent in the 1990s. In the 1990s, it was negative, for example, in the period 1991 to 1994. In 1990 it increased to 2.5 percent from 1.4 percent in 1989 before attaining a record low of –6.9 percent in 1993 (see figure 9). For the period 2000 to 2018, foreign direct investment averaged 2.8 percent, whereas private investment averaged 20.1 percent. In 2000, foreign direct investment was recorded at 1 percent before declining to 0.56 in 2001. Then in 2002, it rose to 7.5 percent, which was the highest for the period 2000 to 2018 before declining to 5.6 percent in 2003. It dropped further to 4.4 percent in 2004 and fluctuated until it reached 1.3 percent in 2018. Figure 9 reflects the foreign direct investment and private investment as a percentage of GDP trends in Botswana from 1980 to 2018.

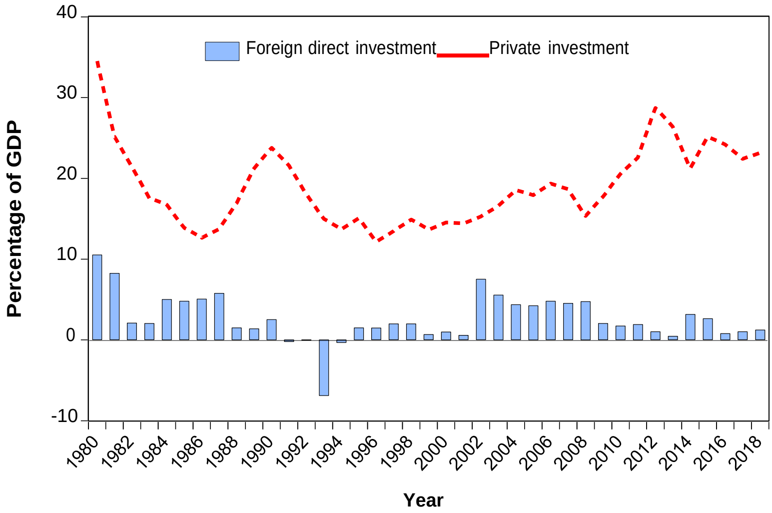

Fig. 9 Foreign Direct Investment and Private Investment in Botswana (1980–2018)
Source: Own compilation from World Bank Development Indicators (2020)

5. Conclusion

In this study, the policies and incentives of the Botswana government to promote private sector investment have been analysed. Since its independence in 1966, the government of Botswana has focused on economic diversification and private sector development. The private sector has been identified by the government as key in driving economic growth and, over many years, developed policies and initiatives to encourage private sector involvement. The government of Botswana has, over decades, implemented a number of incentives aimed at providing finance for investment. These include the FAP, which was established in 1982 with the aim of providing assistance to new and expanding enterprises, and the SMMEs, which were established in 1999.

This study also examined the macroeconomic drivers of private investment in Botswana in the period 1980 to 2018. The drivers include economic growth, public investment, credit to the private sector, gross domestic savings, openness of the economy, interest rate, inflation, and foreign direct investment. The findings of the study show that the policies that the government has implemented to promote the private sector have been working, as shown by the upward trend recorded during the periods, such as 1986-1990, 2001-2004, and 2008-2012. Since the 1980s, the private sector investment has been fluctuating between 34.5 percent and 12.1 percent with the highest level being recorded in 1980 and the lowest in 1996. The study shows that economic growth averaged 6.4 percent, public investment was 10.3 percent, credit to the private sector was 18.3 percent, gross domestic savings was 35.9, trade openness was 101.4 percent, interest rate was 3.6 percent, inflation was 8.9 percent and lastly foreign direct investment was 2.6 percent during the study period. In the current study, the exploratory approach is used to analyse the key determinants of private investment and the co-movement between private investment and its determinants. It is recommended that future studies use empirical analysis and consider modern econometric techniques to examine the relationship between private investment and its determinants. The study is also mainly focused on the macroeconomic determinants; therefore, future studies can look at other drivers of private investment, such as institutional drivers that can explain the performance of private investment.

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POKRETAČI INVESTIRANJA U PRIVATNI SEKTOR U BOCVANI: ISTRAŽIVAČKI PREGLED

Ovaj rad se bavi pokretačima investiranja privatnog sektora u Bocvani za period od 1980 do 2018. Rad analizira investicione politike koje je vlada usvajala tokom godina, podsticaje, kao i institucije koje su uspostavljene da bi se promovisale investicije u privatni sektor. Razvojna strategija vlade Bocvane usmerena je na promovisanje ekonomskog rasta putem privatnog sektora. Neke od ključnih determinanti privatnih investicija, koje se analiziraju, uključuju ekonomski rast, javne investicije, bruto društvenu štednju, otvorenost tržišta, kamatne stope, inflaciju i strane direktne investicije. Od 1980ih, investicije u privatni sektor fluktuišu između 34.5 procenata i 12.1 procenta, pri čemu je najviši nivo zabeležen 1980 a najniži 1996. godine. Studija pokazuje da je ekonomski razvoj u proseku bio: 6.4%, javne investicije 10.3%, krediti za privatni sektor 18.3%, bruto društvena štednja 35.9%, otvorenost tržišta 101.4%, kamatna stopa 3.6%, inflacija 8.9% i najzad strane direktne investicije su bile 2.6 procenata za vreme perioda istraživanja.

Ključne reči: *investiranje u privatni sektor, ekonomski rast, determinante, politike, Bocvana*

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Original Scientific Paper

FLOOD RISK VULNERABILITY VISUALIZATION FOR SUSTAINABLE RISK MANAGEMENT - THE CASE OF SERBIA

UDC 005.334(497.11)

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Abstract. *The main objective of this study is to visualize the flood risk vulnerability of municipalities in the Republic of Serbia through mapping and spatial analysis of precipitation data and data related to the losses. GIS tools enable spatial analysis and visualization of historical data on losses combined with temporal and geo-spatial distribution of precipitation, and QGIS tool was used for visualization of precipitation data and data on damages caused by floods and flash floods. As a result of these analyses, areas with potential high risks of losses are detected, which enables undertaking appropriate steps and measures in order to minimize future losses.*

Key words: *risk visualization, floods, GIS, spatial analysis*

JEL Classification: C63, C82, C88, Q54, Q01

1. INTRODUCTION

Climate change is becoming the primary environmental challenge in the 21st century. Society and economy are exposed to numerous risks which can significantly affect their development. Realization of these risks can cause material and non-material damage. It is important, both from the individual point of view and from the national point of view, to work on the identification, monitoring and prevention of the same risks. Thus, extreme

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risks, natural disasters and climate change are important issues that occupy the attention of the scientific public, but also of policy makers due to the negative socio-economic consequences they may have.

The region of South East Europe is very vulnerable to climate change. Heavy rainfall and subsequent flooding in May 2014 can be considered an extremely important factor affecting the regional growth, because the floods that hit this region indicated a high degree of vulnerability and unpreparedness of countries in this region to manage such risks. Considering the fact that 17.1% of the territory and 17.5% of the population of the Republic of Serbia are at risk of natural disasters, it can be concluded that Serbia is a country of "relatively high risk of multiple hazards" (Dilley et al., 2005). Moreover, according to the projections of climate change, it can be presumed that present hazards, especially hydrological ones, may intensify (Vuković et al., 2018). This alarming estimation provided incentive for the development of improved approaches and policies for flood risk management across Europe.

Selecting an optimal risk management strategy and minimizing the negative effects of floods depends on the accuracy of precipitation assessment. Precipitation, as one of the most important parts of the Earth's water cycle, has very important role for environment and life processes, but also can have destructive role causing losses and damages. The focus of this paper is on mapping and spatial analysis of measured precipitation values using GIS tools and techniques.

The main objective of this study is to visualize the flood risk vulnerability for sustainable risk management in the Republic of Serbia through mapping and spatial analysis of precipitation data and data related to the losses. Thus, the aim of this study is twofold. The first goal is to obtain the precipitation map for the whole territory of the Republic of Serbia and to visually present registered losses. Subsequently, we intend to investigate which areas have higher risk potential caused by heavy rains and flash floods. The paper is structured as follows: section 2 provides an overview of the types and consequences of natural disasters, especially floods, and possibilities for spatial analysis of these disasters using GIS tools; data and methodology are described in section 3 and obtained results are presented in section 4, and section 5 concludes the presented work.

2. Literature Review

A thorough knowledge on natural disasters and their short- and long-term effects on the economic system is critical precondition for conceptualization of effective mechanisms and procedures of disaster risk management. The level of economic development (Raschky, 2008), as well as employment, education and age structure of inhabitants (Noy, 2009) are some of the main determinants of national and regional society's vulnerability to natural disaster losses. Considering the effects of natural processes on the human community, as well as the effects of human activities on shaping the environment, it can be concluded that there is a strong bi-directional and multidimensional relation between natural and social processes (Kovačević-Majkić et al., 2014). The changes in climate parameters already affect GDP, as well as revenues within sectors which are particularly important to the growth and development of the Serbian economy – agriculture and production, transmission and distribution of electric power and heat energy (World Bank, 2015). Moreover, given the expected climate changes, the impact on the GDP of the Republic of Serbia is expected to continue. It is also apparent that the negative influence of climate change on the GDP is increasing with the rise in mean global temperatures (Božanić and Mitrović, 2019, p. 6). Although exposed to multiple types of natural hazards, flooding is a recurring risk that largely varies depending on exposure, vulnerability and coping capacity (Stanković, Tomić & Stanković, 2020). The floods, that are caused by prolonged intervals of rainfall and intensive snow melting, “are occurring most frequently in the Vojvodina region and along with the river courses of the Sava, Drina, Velika Morava, Južna Morava and Zapadna Morava”. Flash floods caused by short intensive rainfall can occur in the smaller river basins (Stat, 2018, pp. 2).

Thus, economic development should be complemented by investments in adapting to climate change and mitigating the effects in order to transform the society in the ongoing transition process. The approach to flood risk management has changed and became more comprehensive and sustainable in order to achieve the financial resilience and minimize the negative effects of natural disasters on the economic growth of the Republic of Serbia (World Bank Group, 2016). This change has been promoted by international actions and legislation, while at the European level the most important act is the European Floods Directive 2007/60/EC, which envisages the development of Flood Risk Management Plans. The development of the Risk Management Plan in areas with significant flood risk is preceded by a preliminary flood risk assessment, preparation of flood hazard maps and flood risk maps.

There are a number of methods for visualizing data which provide different possibilities for analysing data and relations hidden in data. Selecting the appropriate visualization method is influenced by the nature of data and the intention of visualization.

Most important analyses enable comparing categorical values (i.e. comparisons between the relative and absolute sizes of categorical values), assessing hierarchies and part-of-a-whole relationships (i.e. breakdown of categorical values in their relationship to a set of values or as constituent elements of hierarchical structures), showing changes over time (i.e. exploit temporal data and show the changing trends and patterns of values over a continuous timeframe), mapping geo-spatial data (i.e. plot and present datasets with geo-spatial properties) and charting and graphing relationships (i.e. assess the associations, distributions, and patterns that exists between multivariate datasets) (Kirk, 2012).

Geographic Information System (GIS) is a special type of information system which enables collecting, storing, analyses and visualization of spatial data. It is convenient for complex research, design and management problems dealing with geo spatial data. With spatial tools and methods, which are part of modern GIS software, users can discover hidden geographic patterns in their data and detect possible spatial relations between studied phenomena. One of the main advantages of GIS systems is that it is an invaluable tool for different visualization and representation of data (Bednarz et al., 2006). Another more important feature is that GIS tools provide spatial analysis.

Spatial analysis is the process of analysing and processing spatial data in order to get valuable insights from data. Important part of the spatial analysis is data visualization. GIS tools enable generation of numerous visualizations of geo spatial-data, and the most convenient are choropleth maps, dot plot maps, bubble plot maps, contour maps, various cartograms and network connection maps. Choropleth maps are a particularly effective way for visualisation of geo-spatial data. Choropleth maps colour the corresponding geographical areas (such as municipalities or countries) in different colours, or the appropriate colour shades (from light to dark), based on quantitative values of the observed variables. This can show a change in value according to location, which makes it easier to spot patterns or deviations in values.

3. Data and Methodology

The Republic of Sebia was selected as the study area, and two data sources were used for analyses. The first source are monthly precipitation data from 26 meteorological stations at the selected territory. The data were obtained from the annual hydrological journals issued by the Republic Hydrometeorological Service of Serbia. The spatial distribution of selected meteorological stations was presented in Fig. 1. Precipitation data for Serbia have been analysed in different contexts started from the trend analysis (Bajat et al., 2013; Gocic and Trajkovic, 2013; Unkasevic and Tosic, 2011) to analysis in the context of droughts and floods (Gocic and Trajkovic, 2014).

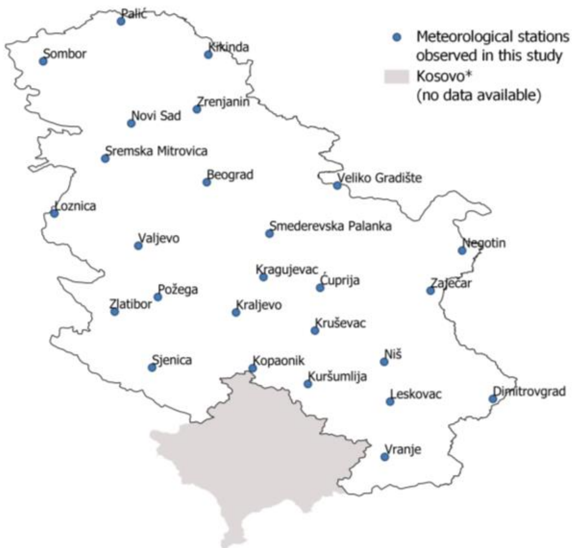

Fig. 1 Distribution of meteorological stations in Serbia
Source: Author's illustration based on data obtained from Republic Hydrometeorological Service of Serbia

Data for the analysis of disasters are obtained from the "DesInventar" database which provides disaster loss data for Sustainable Development Goals and which is developed under supervision of United Nations Office for Disaster Risk reduction (UNISDR). DesInventar offers "tools for the generation of National Disaster Inventories and the construction of databases of damage, losses and in general the effects of disasters". It contains spatial and temporal data, types of events and causes, sources of damages and both direct and indirect effects (deaths, houses, infrastructure, economic sectors etc.). The second tool is Analysis module which allows data queries for obtaining desired data and presenting that data with tables, graphics and thematic maps. It is an open-source software, free of charge, with aim to provide disaster loss data for Sustainable Development Goals. This database provides very detailed information on the effects of all types of disasters such as Drought, Earthquake, Explosion, Fire, Forest Fire, Flash Flood, Flood, Frost, Hailstorm, Landslide, Rains, Snowstorm, Storm, Windstorm etc. Every data entry represents single event and describes it in detail by 140 attributes such as disaster type, location of the event, time and effects of disasters (e.g., people directly and indirectly affected, number of houses destroyed or damaged etc.) The data on disaster events for the Republic of Serbia are available for the 40-year period since 1980 till 2021, and database contains a total of 2,175 data entries. The most dominant events are Forest fire (26.71%), Flood (25.79%), Fire (13.38%), Hailstorm (13.38%) and Snowstorm (6.80%). Quality of data is not so good for earlier entries, but it has improved during time and is very detailed with numerous attributes describing each event. Publicly available dataset enables us to perform different types of analysis, including multidimensional analysis using online analytical processing (OLAP), Power pivot, geospatial analysis, and numerous data mining algorithms. The aim of these analyses is grouping data by disaster type (e.g., Flood and Flash flood), spatial dimension (e.g., Municipality or Region) and time dimension (e.g., Year), and visualization and different kind of analysis of this data from a desired perspective. According to the analysis of the temporal distribution of damages caused by floods, flash floods and landslides in the period between 2010 and 2020 (Table 1.), period between June and August 2018 was chosen for further analysis as a period with biggest number of damages caused by intensive rains in some regions of the country.

Table 1 Temporal distribution of damages caused by floods, flash floods and landslides (2010-2020)

Month	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Jan	19	1	1	4	1	8						34
Feb	7	3	7	5		1		4				27
Mar	2	2	5	12	1	16	13		20	4		75
Apr	17	1	1	2	37	3	1		6	7		75
May	3	3	14	3	39	3				2		67
June	9		11		1	2	3	3	19	19	41	108
July	3	2	4		5	1	2		15	1	1	34
Aug	1	1	1		4	1	1		6		2	17
Sept	2	1			7							10
Oct	1	1										2
Nov	4	1					2	1				8
Dec	11	1										12
Total	79	17	44	26	95	35	22	8	66	33	44	474

Source: Author's illustration based on data obtained from DesInventar data base

Considering the fact that natural risks mainly influence the subsistence of people who live in rural areas and/or small municipalities, analyses of the socio-economic impacts of natural disasters will be performed in the terms of the regional development of the Republic of Serbia. The general data on the development of the regions in Serbia are presented in Table A1 in Annex.

GIS software, as mentioned before, is a commercial or open-source software for dealing with geo spatial data. For the analysis and visualization of data Quantum GIS (QGIS), Open-Source tool free of charge was used, which is very similar to ArcMap and other commercial

GIS tools, offering powerful features for mapping and visualizing data. It offers users friendly interface and support for various datatypes, one of the most useful being shapefiles for presenting geographic areas. QGIS package release 3.16, which can be obtained from qgis.org/en/site was used for data mapping.

Shapefile with a map of the Earth for Serbia was imported as a basic layer with country borders. Second layer was created for presenting geographical position of 26 meteorological stations, and precipitation data from these stations were interpolated to present geospatial distribution of the amount of precipitation for the chosen period (period June-August 2018). Since there are only 26 available meteorological stations in the Republic of Serbia, which are not evenly spread across region, obtained information is limited to the meteorological stations, that means discrete points in space. Interpolation techniques are required for mapping corresponding meteorological variables for the whole Republic of Serbia. Precipitation map for whole country was made using spatial interpolation process in which points with known values are used for estimating values at unknown points in space. Spatial interpolation can estimate the precipitation values at locations without available data by using precipitation data at nearby meteorological stations. A suitable interpolation method has to be used for estimating the values at those locations where no samples or measurements were taken. Numerous spatial interpolation methods have already been developed for supporting transformation from point data to continuous surface map. Those methods can be divided into geographical statistics, non-geographical statistics and hybrid approach. Inverse Distance Weighting (IDW) interpolation method was chosen, as widely used for interpolation in spatial analysis and available in most GIS tools (Li et al., 2018). In the IDW interpolation method, the sample points are weighted during interpolation in such a way that closer point have higher impact and the influence of points declines with increasing distance from the point whose value is interpolated. As a result of interpolation process, a precipitation map was created for the whole region of Serbia.

Since available data about disasters are based on geographical regions (municipalities) it could be plotted as a layer on the map. Shapefile with a map of the Earth for Serbia was imported as a layer with municipality borders. Second layer was created for presenting numerical data describing disasters, and after joining map shapefile and data, that data was used to determine the colours of the map for each municipality – greater values are presented with darker colour according to defined scale.

4. Results and Discussion

Geospatial distribution of precipitation for the period June-August 2018 in Serbia is presented in Fig. 2. According to the previously published analysis of precipitation data for the period 1946-2019 (Gocić et al., 2021), the west part of the country is the wettest part while the northern and southern parts of the country are dry. According to Fig. 2, some irregularities in precipitation distribution can be observed. Mountains Zlatibor, Kopaonik and Crni Vrh had significant values of the precipitation (more than 300 mm), and municipalities with the greatest values of the total precipitation in the analysed period are Požega, Kraljevo and Sjenica with 330.7, 321.3 and 268.5 mm, respectively. The lowest amount of precipitation was in south-east part of the country in municipalities Vranje, Negotin and Niš (97.7 mm).

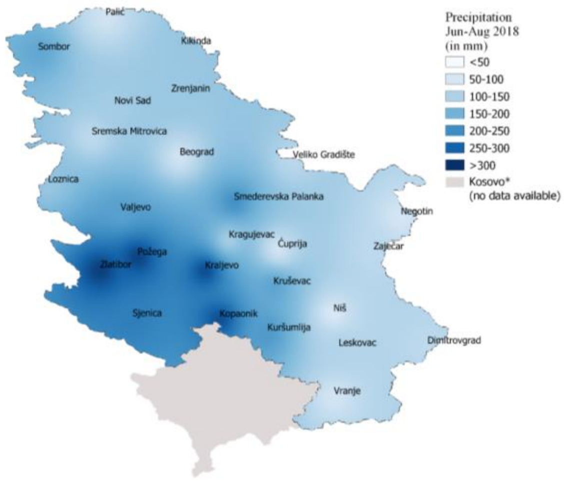

Fig. 2 Geospatial distribution of precipitation for the period June-August 2018
Source: Author's illustration

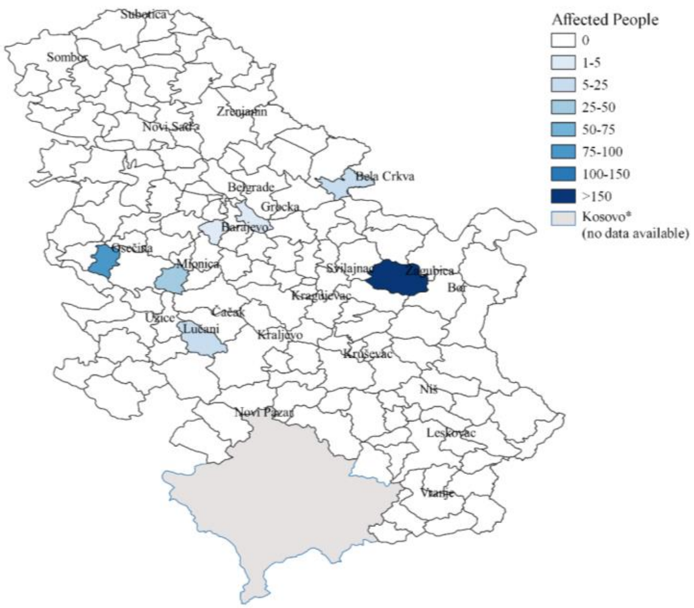

Fig. 3 Geospatial distribution of people affected by floods and landslides
Source: Author's illustration

Five municipalities in Serbia (Žagubica, Osečina, Mionica, Lučani and Bela Crkva) were identified as the most vulnerable concerning the number of affected people by floods and landslides as a result of increased precipitation in the analysed period (Fig. 3). More than 20 people were affected in each of those municipalities, and the largest number of affected people was in Žagubica i.e., 419. Four out of five vulnerable municipalities territorially belong to the regions of Šumadija and Western Serbia and Southern and Eastern Serbia, which are characterized by large number of small municipalities. In the case of these regions, close to 2,000 municipalities are located in the area of approximately 26,000 km^2. Having in mind this fact, it can be observed that every-day life and work of people in small and underdeveloped municipalities are highly affected by the flood risk.

Geospatial distribution of destroyed and damaged houses in Serbia is presented in Fig. 4. The number of destroyed and damaged houses greater than 500 houses was recorded on the territory of two municipalities (Petrovac na Mlavi and Kraljevo). Aranđelovac and Žagubica had the number of damaged houses between 250 and 500, while Čačak had 182 damaged houses. In relation to the material damage, it can be noticed that the number of destroyed and damaged houses is especially great in the municipalities located in the Region of Šumadija and Western Serbia. Considering the level of GDP per capita in this region, it is evident that people in the least developed regions suffered the most severe damage of their properties.

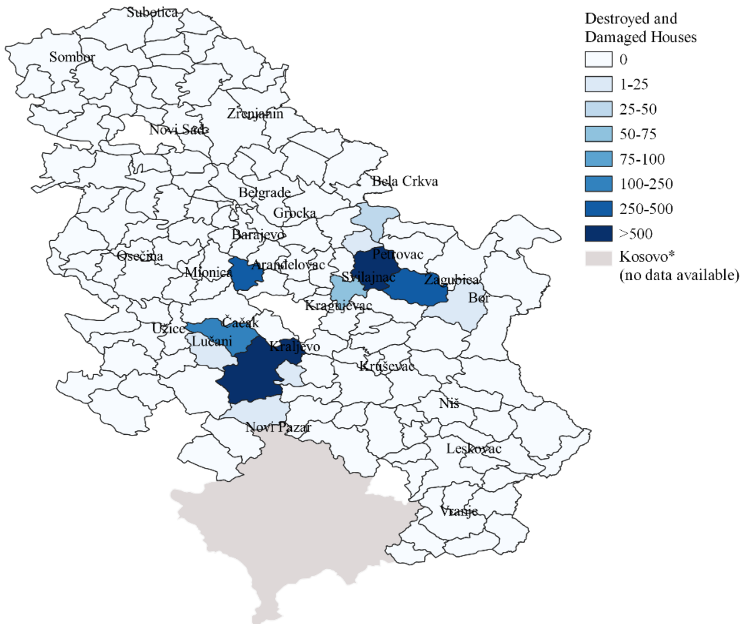

Fig. 4 Geospatial distribution of destroyed and damaged houses
Source: Author's illustration

If we take into consideration the share of agriculture, forestry and fishing in GDP creation, the regions of Vojvodina (14.9%) and Šumadija and Western Serbia (11.4%) are especially dependent on the efficiency of this industry. Therefore, damage to crops may be examined as the indicator of the impact of natural disasters on the economy of the Republic of Serbia. Geospatial distribution of damages on crops is presented in Fig. 5. In total, thirteen municipalities were identified as a vulnerable. The damages were presented in hectares. The most significant damages on crops, on more than 1000 Hectares, were recorded in three municipalities (Velika Plana, Petrovac na Mlavi and Priboj). Important observation is that there were serious damages on crops in the municipalities Velika Plana and Priboj which are not followed by other damages, while in Petrovac na Mlavi there were numerous destroyed houses also. Although the manifestation of flood risk can be prevented, the concerning fact is that its influence on agriculture in the areas, where this industry is of special importance for economic development, is not mitigated.

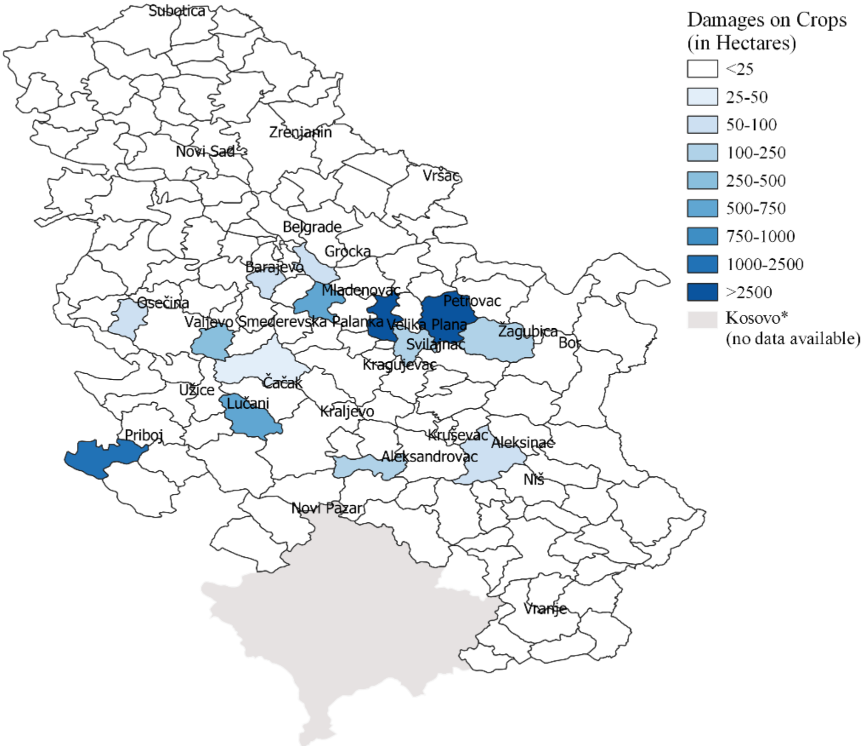

Fig. 5 Geospatial distribution of damages on crops
Source: Author's illustration

Considering economic losses, the observed database records of the losses caused by natural disasters at the territory of the Republic of Serbia are presented in the local currency and only for 30.17% cases. The largest number of economic losses is available for the Region of Šumadija and Western Serbia (47.35%) and the Region of Southern and Eastern Serbia (30.57%), while the largest number of records concerns flood damage (46.92%). Geospatial distribution of losses in million RSD is presented in Fig. 6. The most endangered municipality was Žagubica, while at the second level of vulnerable municipalities were Petrovac na Mlavi, Grocka and Lučani.

Detailed data on losses showed that Žagubica had the biggest losses in the observed period in all categories – 419 affected people, 304 destroyed and damaged houses, 200 Hectares of damages on crops. Unfortunately, since there is no meteorological station in Žagubica, interpolated precipitation visualization for that part of the country is not precise. Detail analysis of losses in the period between 2010 and 2020 on the territory of municipality of Žagubica shows that there were losses also in 2014 and 2020, the most significant are damages on crops – 320 Hectares in 2014 and 300 Hectares in 2020.

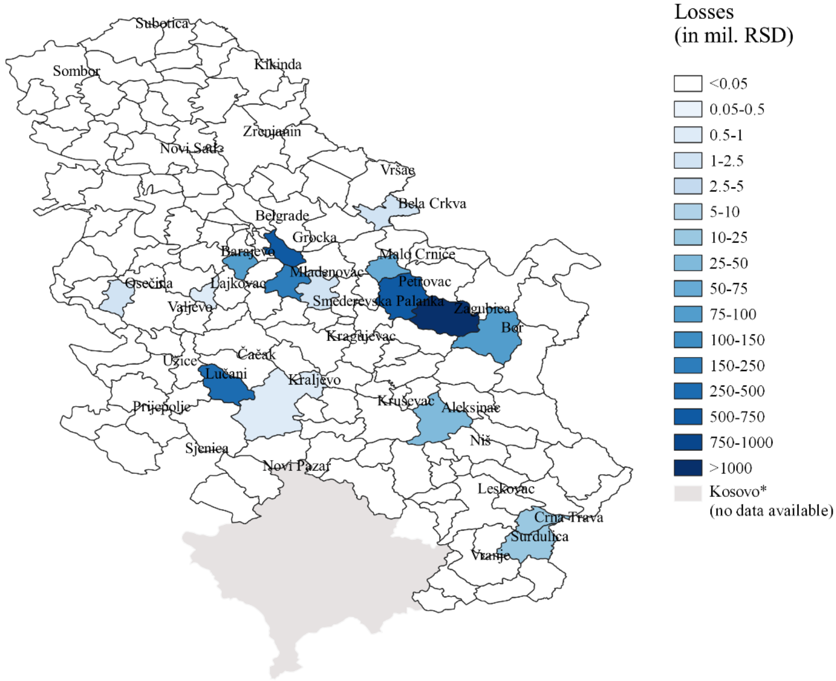

Fig. 6 Geospatial distribution of losses in million RSD
Source: Author's illustration

5. Conclusion

Flash floods have a serious impact on society and economy. These events commonly occur on the limited areas and spread up to a few hundreds of square kilometres (Gaume et al., 2009). However, flash floods are the most dominant and severe hydrological risk in a number of countries. The floods are among the most frequent risk in the Republic of Serbia, i.e. 25.79% of all losses are caused by floods. The spatial distribution of damages related to floods in the Republic of Serbia, despite the different geographical characteristics of the observed regions, indicates that this risk causes greater damage to the property and crops to people in less developed regions. Thus, the municipalities in the regions of Šumadija and Western Serbia and Southern and Eastern Serbia, which are most exposed to hydrological risks, are suffering the greatest socio-economic effects of floods. The fact that flood risk is the common seasonal risk in these areas indicates the need for thorough analysis of the effects and dynamics of these risks. Comprehensive information on flood risks could enable prevention of large-scale disasters and efficient disaster risk management. Despite expectations, the average consequences of floods are increasing. Large material and economic losses affect the existence of people in these areas. This situation reveals the scarcity of firm empirical evidence on the socio-economic consequences of natural disasters leading to the inadequate flood risk assessment and consequently exiguous strategy for disaster risk management. Aiming to minimize the negative effects of floods, local communities face numerous challenges to transform information about precipitation into tangible implications on vulnerability and implement obtained results into concrete measures. Thus, the importance of precipitation mapping is growing considering that visual information is better communicated to different experts, as well as communities and policy-makers, whose involvement in sustainable flood risk management is necessary.

GIS tools enable spatial analysis and visualization of historical data on losses (caused by flash floods, floods and landslide as a result of heavy rains) combined with temporal and geo-spatial distribution of precipitation. As a result of these analyses, areas with potential high risks of losses could be detected, and appropriate steps and measures could be undertaken in order to minimize future losses. Spatial analysis and comparison of precipitation maps and maps of losses show that there are some areas with significant losses, while other areas are not affected with similar amount of precipitation. This indicates the need to analyse landscape, geology and spatial, as well as social and economic determinants of flood risk vulnerability. Since there are only 26 available meteorological stations in the Republic of Serbia, which are not evenly spread across region, available information is limited to the location of meteorological stations and, therefore, to discrete points in space. Precipitation data for other regions is obtained by interpolation techniques, which inputs bias in analyses. Using radar and satellite data on precipitation, instead of data from rain gauges, and/or using more sophisticated interpolation algorithms, could improve analyses and provide better detection of areas with potential risk of flooding, particularly for flash floods in small catchments driven by extreme rainfall intensities over short durations.

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VIZUELIZACIJA RANJIVOSTI OD RIZIKA POPLAVE U SVRHU ODRŽIVOG UPRAVLJANJA RIZIKOM – PRIMER REPUBLIKE SRBIJE

Osnovni cilj ove studije je vizuelizacija ranjivosti opština u Republici Srbiji od poplava kroz mapiranje i prostornu analizu podataka o padavinama i gubicima. GIS alati omogućavaju prostornu analizu i vizuelizaciju istorijskih podataka o gubicima u kombinaciji sa vremenskom i geoprostornom distribucijom padavina, a QGIS alat je korišćen za vizuelizaciju podataka o padavinama i podataka o štetama nastalim od poplava i bujičnih poplava. Kao rezultat ovih analiza detektovana su područja sa potencijalno visokim rizicima od gubitaka, što omogućava preduzimanje odgovarajućih koraka i mera u cilju minimiziranja budućih gubitaka.

Ključne reči: *vizuelizacija rizika, poplave, GIS, prostorna analiza*

APPENDIX

Table A1 Regions in the Republic of Serbia – general data for 2018

Regions	Number of municipalities	Area (km^2)	Number of inhabitants*	GDP per capita (000 RSD)	GVA agriculture, forestry and fisheries
Belgrade region	174	3,234	1,690,193	1,240	1.1%
Vojvodina region	446	21,614	1,861,863	705	14.9%
Region of Šumadija and Western Serbia	1,935	26,493	1,924,816	489	11.4%
Region of Southern and Eastern Serbia	1,967	26,248	1,505,732	476	8.5%

* Estimation made on June 30, 2018

Source: Authors' calculation, based on the data from the Statistical Office of the Republic of Serbia

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