CEREM

CENTRAL EUROPEAN REVIEW OF ECONOMICS AND MANAGEMENT

Vol. 6, No. 3, September 2022

ISSN 2543-9472
e-ISSN 2544-0365

WSB University in Wrocław

Wyższa Szkoła Bankowa we Wrocławiu

CENTRAL EUROPEAN REVIEW OF ECONOMICS AND MANAGEMENT

Volume 6, Number 3
September 2022

Vol. 6, No. 3

Publisher: Wyższa Szkoła Bankowa we Wrocławiu (WSB University in Wroclaw)
ul. Fabryczna 29-31, 53-609 Wrocław, Poland

Contact: Johannes (Joost) Platje, johannes.platje@wsb.wroclaw.pl, ul. Fabryczna 29-31, 53-609 Wrocław, Poland

The journal is reviewed according to the principle of double blind peer review, as well as in compliance with the standards of the Polish Ministry of Science and Higher Education. CEREM is a continuation of the WSB University in Wrocław Research Journal (Zeszyty Naukowe WSB we Wrocławiu – ISSN 1643-7772; eISSN 2392-1153)

CEREM is registered in the IC Journal Master List, and indexed in the Central and Eastern European Online Library (CEEOL), Index Copernicus, Google Scholar, EconStor, BazEkon and ERIH PLUS.

ISSN 2543-9472; eISSN 2544-0365
Cover and logo design: Sebprojekt.pl
Publisher: Wyższa Szkoła Bankowa we Wrocławiu (WSB University in Wroclaw), ul. Fabryczna 29-31, 53-609, Wrocław, Poland

CONTENTS

CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

ISSN 2543-9472; eISSN 2544-0365

Vol. 6, No.3, September 2022, 7-32

www.cerem-review.eu
www.ojs.wsb.wroclaw.pl

Blockchain technology in supply chains – improving end-to-end business performance

Cees J. GELDERMAN, Janjaap SEMEIJN, Niels SMIT

Open University of The Netherlands

Received: 09.08.2022, Revised: 12.09.2022, Accepted: 12.09.2022
doi: http://dx.doi.org/10.29015/cerem.956

Aim: Blockchain technology (BCT) is a relatively new technological development, promising strong gains in the areas of product traceability and visibility, end-to-end coordination (E2E), governance, and efficiency of supply chains. The aim of this study is to gain a better understanding of the impact of BCT on these performance measures.

Design / Research methods: Hypotheses were tested with survey data from 119 supply chain professionals from Northern American SMEs.

Conclusions / findings: The results confirm the positive impacts of BCT on all performance measures. E2E coordination is the integration of information, goods, and money within an organisation or supply chain. E2E coordination appeared to benefit from the use of BCT, enabling information sharing in a safe way. The findings suggest that BCT use fosters E2E coordination, which in its turn also positively affects financial performance.

Originality / value of the article: Despite the increasing interest in and use of, BCT, there is little empirical evidence for the effect on supply chain performance. Many studies are anecdotal and lack empirical evidence.

Implications of the research: Companies should acknowledge the impact of BCT use on the various supply chain performance measures. Implementing and using BCT is likely to foster improvement in a wide range of performance indicators.

Limitations of the research: Companies use different types, versions, varieties, and forks of blockchain, all having their own strong and weak points. Future studies could investigate and include the nuances within different forks of BCT. This study focusses on the benefits of BCT use. Future studies could investigate the negative impacts and side-effects of BCT.

Key words: Blockchain technology, product traceability, operational efficiency.
JEL: M1

Correspondence address: Cees J. GELDERMAN, Janjaap SEMEIJN, Niels SMIT, Open University of The Netherlands, Valkenburgerweg 177, 6419 AT Heerlen, The Netherlands. E-mail: gel@ou.nl (Cees J. GELDERMAN), janjaap.semeijn@ou.nl (Janjaap SEMEIJN), niels.c.smit@gmail.com (Niels SMIT).

1. Introduction

Current organisations are eager to increase the effectiveness and operational strength of their business (Becker, Kahn 2003; Vo et al. 2019). Continuous outsourcing and specialisation have typically increased the emphasis on cost reduction of organisations and have therefore led to the increased need to optimize their competitiveness and performance. One way to improve the performance of an organisation is to increase the performance of its supply chain (Söderberg, Bengtsson 2010; Tortorella et al. 2018).

Within the last few decades, a large array of technological advances and developments have been introduced to the world (Alicke et al. 2019), with many organisations adopting and implementing these technological solutions in search of operational or organisational performance gains (Casado-Varaa et al. 2018). This search has led to many costly dead-ends, in cases where technology could not succeed in delivering the increase in performance that they promised (Alicke et al. 2017). In some cases, these solutions even came with their own set of new problems; for example, in the case of the usually inflexible and rigid manufacturing-resource-planning (MRP) (Umble et al. 2003). MRP software often cannot deal with 'uncertainties and volatilities of the real world, in which machines break down, suppliers fail to deliver, and customers change their minds' (Alicke et al. 2017).

In many cases, it has become clear that technological advancement and solutions can never take the place of operational quality and the use of best practices within supply chains, such as effective cross-functional collaboration (Laurent, Leicht 2019), adherence to the pillars of the SCOR model (McCormack et al. 2008; Miri-Lavassani, Movahedi 2018), or ensuring that the organisation's employees are a good fit within the team (Kooij, Boon 2018).

Current organisations and supply chains, however, have a wide selection of promising technology at their disposal, many of which have cascaded down from different kind of fields, such as blockchain technology (BCT), the Internet-of-things, artificial intelligence (AI), or the general push for digitisation. What most technologies also have in common is that they all promise substantial performance gains.

The three areas of technological innovation that deserve a better understanding to what extent they are driving organisational performance in modern supply chains, are end-to-end (E2E) coordination, BCT, and traceability. These areas have attracted much attention, both academically and professionally, throughout recent history (Tjahjono et al. 2017; Tortorella et al. 2017; Hill et al. 2018; Nandi et al. 2020), and have been claiming specific performance gains, either in error reduction (Salah, Rahim 2018), improving product visibility (Treiblmaier 2018), or improving supply chain efficiency (Alicke et al. 2019).

Despite the increasing recent interest in, and use of, BCT, there is little empirical evidence for the effect it has on supply chain performance (Casado-Varaa et al. 2018); many studies are anecdotal and lack empirical evidence. To study the effects that these new developments have on the performance of supply chains, a quantitative survey was carried out among supply chain professionals from North American SMEs.

2. Literature Review

2.1 Blockchain Technology

BCT is generally referred to as a distributed data structure, a decentralised network, or, most commonly, distributed ledger technology (DLT) (Kshetri 2018). BCT was introduced for the first time, at least in the context of the Bitcoin protocol, in 2008 (Nakamoto 2008). The technology was introduced by the person, or group of people, that goes by the name of Satoshi Nakamoto (Nakamoto 2008; Seebacher, Schüritz 2017). With the introduction of the technology by Nakamoto, it became useable as a protocol that is open, transparent, and secure and eliminates the need for a central governing body (Seebacher, Schüritz 2017).

BCT can be used to record and store information in blocks. Each block of information contains a hash of the previous block, a timestamp, and the data of the actual transaction (Wonga et al. 2019). These blocks of information can contain financial transactions, personal information, or messages between people or organisations. BCT is unique in the sense that information is not stored in one central location but is managed entirely decentralised, making it difficult to corrupt. Its

transactions, which are time stamped (Sharples 2016), are published and shared with all other users within the chain and are stored in the network using peer-to-peer technology. The verification process, in combination with the used encryption, secures the data so that only authorised members have access to the information in the blockchain (Wang et al. 2018). Since 'trust' is coded into the blockchain, there is no need for central governing bodies (Gaehtgens, Allan 2017). When the transaction is verified and authorised by at least 51% of the users in the specific chain, the information is added to a new block. This system makes it easy to check which subsequent blocks of information are related to each other, which makes the technology '*secure by design*' (Falazi et al. 2019).

2.2 Blockchain Technology in Supply Chains

BCT is generally considered to be an emerging, foundational technology. In September 2015, nine financial institutions including Goldman Sachs, J.P Morgan and Barclays, built a new financial infrastructure that was based on BCT (Underwood 2016). As a result of this, many young companies in the Fintech industry were founded that based their business upon this new technology. Supply chains were somewhat slower to understand the potential of the technology but have since been implementing and restrategising the still young technology (Hackius, Petersen 2017). One of the major performance gains for supply chains that the use of BCT should result in is to give all nodes in the entire supply chain network access to the same data, resulting in unanimous agreement among the whole network (Tapscott, Tapscott 2018). Furthermore, in the area of transparency and visibility, which are traditionally difficult areas to improve, BCT should result in significant gains (Abeyratne, Monfared 2016). Furthermore, BCT is showing also considerable promise in terms of traceability, which has gained substantial traction in recent years, from both legal and ethical points of view (Dabbene et al. 2014). As a result, both from the professional and academic world, the use of BCT is considered to offer considerable promise and potential for supply chains (O'Marah 2017) or is even able to 'transform the supply chain and disrupt the way we produce, market, purchase and consume our goods' (Dickson 2016). Several sources cite and assume BCT to be a 'disruptive' technology (Treiblmaier 2018), but according to the definition of Iansiti and Lakhani (2017), the

term ‘foundational’ as applied to this technology would be more appropriate, as it can lead to the ‘enabling’ of many other types of technology and developments (Iansiti, Lakhani 2017; Hald, Kinra 2019; Buer 2019).

Studies have shown that the use of BCT can indeed lead to higher levels of reliability, transparency, and efficiency through its unique set of characteristics (Treiblmaier 2018). Furthermore, Kshetri (2018) found that the implementation and use of BCT strongly correlated with several typical performance indicators commonly used in SCM, such as cost, speed, and flexibility. It is believed that BCT can lead to these improvements through a large array of applications, on which Petersen et al. (2017) has performed a study in which 49 different applications where BCT could be used were studied. These applications were then grouped into three main clusters: product tracking, product tracing, and supply chain finance.

In contrast, in the same study by Petersen (2017), it was also shown that there remain large numbers of conservative organisations that are hesitant to invest in and implement BCT by claiming that it is unclear exactly how the use of BCT can lead to performance improvement and how it is affecting the employees of organisations. This might be the result of having little knowledge about blockchain (Kersten et al. 2017), uncertainty about the barriers to implementation (Hackius, Petersen 2017), or fear of BCT being hype (Banker 2017). Furthermore, scepticism remains regarding the general innovativeness and applicability in the real world or an association with money laundering (Cong, He 2019).

2.3 Product Visibility and Traceability

In recent developments, BCT has been proposed to provide increased levels of traceability and standardisation in communication and data formats (Westerkamp et al. 2020). The use of BCT can in this way serve as a foundational technology in order to enable or improve traceability (Francisco, Swanson 2018). It is able to do this by enabling the users of the technology to attach a record of information to the blocks of information within the blockchain that contain all the product’s history (Ølnes et al. 2017). Records of information are added during all transactions between blocks, are stored for an infinite amount of time, and are indelible and impossible to adjust or modify. In the case of private blocks, the information records are only available to

predetermined members. When the records need to be publicly available, the public blockchain is used. The use of BCT in supply chains could therefore lead to a higher level of visibility of the status, position, and condition of information or goods within the whole supply chain, which is argued to lead to higher levels of traceability (Hald, Kinra 2019).

2.4 End-to-End Coordination

End-to-end coordination (E2E coordination) is the integration of all flows of information, goods or money within an organisation or supply chain. It is generally argued that in order to achieve successful supply chain collaboration, actors within a supply chain are required to approach supply chains with a holistic and end-to-end perspective (Burnette, Dittmann 2018). This is the result of the notion that any decision or action in any part of a supply chain can affect results in all other areas. These decisions and actions, therefore, need to be understood by the actors within supply chains to manage, improve and ultimately reach end-to-end coordination and collaboration (Burnette, Dittmann 2018). Historically, supply chains without collaboration or end-to-end coordination have typically endured additional costs or have struggled with customer relations more than supply chains with more advanced E2E coordination (Alicke et al. 2019; Burnette, Dittmann 2018).

It is generally believed that higher E2E coordination will lead to better organisational performance of the supply chain through better visibility, control and traceability of the products, services or pieces of information that is contained within the supply chain (Alicke et al. 2019; Yu et al. 2017). The study by Alicke et al. (2019) shows that supply chains with higher-than-average performance have higher levels of investment in formal roles created to improve E2E coordination across their business units, functions, and sites.

By improving E2E coordination, participants and actors are more likely to understand the location of goods in transit, they will be able to determine the status of customs documents more efficiently and view other types of data in more efficient or less restrictive ways (Nowiński, Kozma 2017). This will lead to a more efficient supply chain. BCT is believed to be able to enable enhanced E2E coordination as a result of the increased visibility of products, goods and information within the supply

chain (Hald, Kinra 2019). BCT can achieve this because of the potential of every node within a blockchain to be able to see all other nodes, and this information is passed on instantly to all participants and actors within the supply chain possessing the predetermined authority.

2.5 Supply Chain Governance and Efficiency

Another potential development that is enabled by the use of BCT is the creation of algorithms that are enforced or executed when certain conditions are met, which is a concept that is also known as a 'smart contract'. Smart contracts were first envisioned in 1994 by Szabo (1996), when he defined a smart contract as "machine-readable transaction protocols which create a contract with pre-determined terms". Several years later, the definition for smart contracts developed into 'a set of promises, specified in digital form, including protocols within which the parties perform on these promises' (Szabo 1996). Smart contracts are not simply digital contracts, nor do they merely rely on the implementation of AI. What makes smart contracts 'smart' is that they allow terms contingent on fully decentralised consensus; are completely tamper-proof; and are fully automated, enforced, and executed when a predetermined set of conditions are met. Because of these characteristics, smart contracts have low transaction fees compared to the traditional systems, which often require a trusted third party such as a notary or legal officer in order to enforce and execute the terms of an agreement.

Smart contracts can run on BCT, where they have the ability to facilitate, execute, and enforce the terms of an agreement. When smart contracts run on BCT, the conditions of the agreement are formulated in code, which is then transferred to a blockchain, which can be either private or public. After the predetermined conditions of the contract are met, the contract is then automatically executed without any assistance or governance of third-parties or central forms of governance. Additionally, by being tamper-proof, it is not possible to change the internal logic or conditions at any time unless there is a consensus of all parties involved. The use of BCT in a supply chain therefore stimulates data availability, visibility, security, and benefits of using common language and terminology (Casado-Varaa et al. 2018). Because of the inherent nature of BCT, the data surrounding the terms and execution of the contract

are visible for all predetermined users and parties involved with the smart contract. It is therefore often argued that organisations can benefit from the use of smart contracts and thus improve the governance and efficiency of their supply chains (Hald, Kinra 2019). These concepts are generally associated with improved supply chain performance (Treiblmaier 2018).

2.6 Supply Chain Performance

Supply chain performance (SCP) is a term that can be explained, defined, and constructed in many different ways (Beamon 1999; Mani et al. 2017). One way to construct SCP is to use organisational performance, operational performance, and environmental performance (Inman, Green 2018). Another way would be to use supplier performance, customer satisfaction, and financial performance as indicators for SCP (Li et al. 2006; Yu et al. 2017; Benton et al. 2020). In this way of looking at SCP, an organisation would be able to understand what is happening at the input and the output side of its supply chain, combined with the financial performance indicators, to be able to understand the performance of its supply chain.

Supplier performance can also be defined in many different ways: quality of the products of the supplier (Mani et al. 2017); the products' lead-time; and the supplier's stability (Chang, Lin 2019), number of errors (Mani et al. 2017), price levels compared to their competition (Li et al. 2006), and other factors. It is essential to know the levels of performance at the supplier side of a supply chain, as supplier performance is a key driver in the overall SCP (Mani et al. 2017; Yang, Zhang 2017; Al-Shboul et al. 2017).

Customer satisfaction is, similarly to supplier performance, an essential driver of overall SCP, as it is a strong indicator for the organisation's own SCP. There exist many ways to measure customer satisfaction (McColl-Kennedy, Schneider 2010), though given the rather subjective nature of it, simply asking a customer to what extent they are enjoying the experience of engaging in business with the other side could be sufficient (Cengiz 2010).

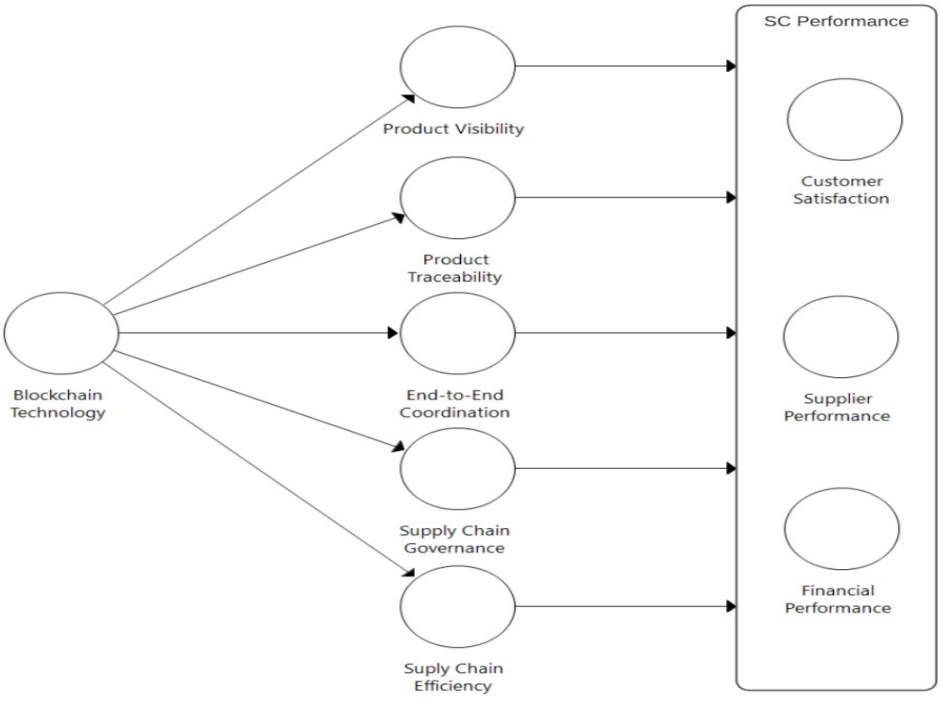
In some cases, customer satisfaction could be defined as a customer 'who receives significant added value' (Hanan, Karp 1989), which is based on the assumption that when a customer received the required product or service, the satisfaction levels will

rise. The financial SCP is a strong indicator for its overall strength and performance and particularly useful as an indicator when it is compared to the financial performance indicators with the industry average (Tortorella et al. 2018).

3. Research model

The literature shows that the use of BCT can improve the performance and effectiveness of a supply chain in several ways. Product visibility, product traceability, end-to-end coordination, supply chain governance, and supply chain efficiency are all areas where supply chains are believed to be able to benefit from BCT. As shown in **Błąd! Nie można odnaleźć źródła odwołania.**, SCP is constructed from customer satisfaction, supplier performance, and financial performance. It can, however, also be measured separately in order to understand the area where BCT has the strongest effect.

Figure 1: Research Model



Source: authors' own elaboration

4. Methodology and instrument

A self-administered survey was conducted between February and March in 2021, using a diverse sample consisting of companies of different sizes, industries, and ages. A Dun and Bradstreet database was used to acquire a large number of contact details of Northern American (including Canada) based supply chain professionals. This type of database was used as they are known for their high-quality data and as it was deemed to be important to acquire both email addresses and telephone numbers of potential respondents. For the selection of the sample of companies, three different criteria were used. The first criterion is that the respondent company should be from a pre-defined region to be able to cancel out the effects that external environments may play (Kull et al. 2014).

The second criterion is that the respondents should be from a diverse range of industries, such as construction, manufacturing, food, fashion, retail, and others, as supply chain development has been expanding in a wide range of different companies throughout the years (Handfield, Nichols 2015). The industry categorisation was carried out using the Global Industry Classification Standard (GICS 2020) on the 'industry' level. The third and last criterion is that the specific respondent that was asked to fill in the survey has a direct relationship to SCM within the company in order to accurately answer the questions in the survey. The higher-ranking person within this scope was preferred, as this tends to be a more reliable source of information (Podsakoff et al. 2003).

The questionnaire used for this study consist of three parts. The first part focused on the level of use of BCT within the supply chain. The items of the first part were developed based on a modified version of the previously tested and validated questionnaire used by Kamble et al. (2018). Secondly, several performance indicators of the supply chain such as product visibility, product traceability, and end-to-end coordination were studied. To measure this, a modified version of the previously tested and validated questionnaire by Al-Shboul et al. (2017) was used. Constructs of this survey were used in a modified form to accurately measure the levels of these performance indicators. Thirdly, the supply chain performance in a more traditional

sense was measured. This was done by focusing on *supplier performance*, *customer satisfaction*, and *financial* supply chain performance.

Table 1. Constructs and measurements

Construct	Variable	Items	Source
Blockchain Technology	BCT Usage		
Performance variables	Product Visibility	Change Information Sharing	*Al-Shboul et al. (2017)*
		Information Sharing with Partners	*Al-Shboul et al. (2017)*
		Core processes information sharing with partners	*Al-Shboul et al. (2017)*
		Informing partners about changing events	*Al-Shboul et al. (2017)*
	Product Traceability	Tracking information within value chain	*Pisani (2018)*
		Location knowledge of manufacturing	*Pisani (2018)*
		Known inventory of primary materials	*Pisani (2018)*
		Production location information available in machine readable format	*Pisani (2018)*
		Efficient tracing back of information	*Pisani (2018)*
	E2E Coordination	All functions with high level of coordination	*Al-Shboul et al. (2017)*
		Cross-functional teams for process design/improvement	*Al-Shboul et al. (2017)*
		Information system integrates through entire organisation	*Al-Shboul et al. (2017)*
		Cross-over activities with partners	*Al-Shboul et al. (2017)*
		Full system visibility shared with partners	*Al-Shboul et al. (2017)*
		Lower cost of distribution than competition	*Al-Shboul et al. (2017)*

Table 2. Cont.

Construct	Variable	Items	Source
	SC Governance	Operational and strategic gains through collaboration	*Khandakar (2009)*
		Different stakeholders working together	*Khandakar (2009)*
		Measuring the responsiveness throughout entire organisation	*Khandakar (2009)*
		Suppliers meeting high quality standards	*Khandakar (2009)*
		Suppliers motivated to minimize SC errors	*Khandakar (2009)*
	SC Efficiency	Return on Investment higher than industry average	*Al-Shboul et al. (2017)*
		Growth in ROI	*Al-Shboul et al. (2017)*
		Profit margin on sales higher than industry average	*Al-Shboul et al. (2017)*
		Overall competitive position	*Al-Shboul et al. (2017)*
		Cost associated with held inventory better than industry average	*Al-Shboul et al. (2017)*
Supply Chain Performance	Supplier Performance	Suppliers meeting delivery schedules	*Benton et al. (2020), Al-Shboul et al. (2017)*
		Suppliers providing efficient operational environment	*Benton et al. (2020), Al-Shboul et al. (2017)*
	Customer Satisfaction	Meeting customer's delivery schedules	*Benton et al. (2020), Al-Shboul et al. (2017)*
		Meeting customer's quality standard	*Benton et al. (2020), Al-Shboul et al. (2017)*
		Providing efficiant operational environment to customers	*Benton et al. (2020), Al-Shboul et al. (2017)*
	Financial Performance	Total cost of recourses better than industry average	*Ishtiaque (2020)*
		Cash-to-Cash Time Cycle better than industry average	*Al-Shboul et al. (2017)*

5. Results

Frequency distributions of the respondents and industries were first examined. As shown in Table 2, the majority (62.5%) of the respondents held the position of manager in their respective companies. No bias due to the respondent's position was found.

Table 2. Position by the respondents

		Frequency		
	Position	**Abs.**	**(%)**	**Cumulative Percentage**
Valid	President	0	0	0
	Manager	70	62.5	62.5
	Consultant	24	21.4	83.9
	Other	18	16.1	100.0
	Not informed	0	0.0	100.0
	Total	112	100	
Total		**112**	**100**	

Source: authors' own research

In total, 26% of the respondents were industrial production companies, 22% were in Health Care, and 20% were in Finance. The remaining 32% were service providers or in retail. No bias for any industry segment was found.

For this study, blockchain-using organisations were targeted. In total, 26% of the respondents reported very low levels of BCT, 69% reported Low or Moderate levels of BCT, and 5% reported High levels of BCT usage.

Factor analysis was used to understand to what extent the used items are relevant to the constructs they are considered part of. To ensure the reliability of the research, items were eliminated from their respective constructs in case the factor loading on their intended constructs was below the minimum recommended level of 0.50 (Hair et al. 2006). After the initial factor analysis, it became clear that some items did not meet the lower threshold of 0.50, and these items were thus removed. After consolidating the research model, the results are as shown in Table 3 and Table 4.

Table 3. Construct reliability and validity

Construct	Items	CA	CR	AVE
(1) Blockchain Technology	1	1	1	1
(2) Product Visibility	5	0.72	0.81	0.47
(3) Product Traceability	5	0.74	0.83	0.49
(4) End-to-End Coordination	6	0.70	0.80	0.40
(5) Supply Chain Governance	6	0.71	0.80	0.41
(6) Supply Chain Efficiency	5	0.68	0.80	0.44
(7) Supply Chain Performance	7	0.77	0.83	0.42

Source: authors' own research

Table 4. Construct validity

	(1)	(2)	(3)	(4)	(5)
(1) Product Visibility	**0.69**				
(2) Product Traceability	0.72	**0.70**			
(3) End-to-End Coordination	0.66	0.74	**0.63**		
(4) Supply Chain Governance	0.54	0.56	0.66	**0.64**	
(5) Supply Chain Efficiency	0.59	0.66	0.68	0.69	**0.66**
AVE	0.47	0.49	0.40	0.41	0.44
Composite Reliability	0.81	0.83	0.80	0.80	0.80

Source: authors' own research

Table 5 shows that the Fornell-Larcker criterion was not reached, which is explained by the relatively low AVE of all five constructs. Therefore, a more elaborate HeteroTrait-MonoTrait (HTMT) ratio of correlations-analysis was performed to understand to what extent issues with multicollinearity might be expected (Henseler et al. 2015).

SmartPLS, version 3.3.3 was used to carry out PLS regression. It can deal effectively with research models that contain highly intercorrelated variables that are surrounded by substantial amounts of random noise (Jöreskog, Wold 1982). To calculate the path coefficients, factor loadings, construct reliability, and validity measures, the regular PLS algorithm was used. To generate the *t*-statistics and *p*-values, bootstrapping based on 3,000 samples was used. This methodology was

consistent throughout this whole research. After loading and running the model in SmartPLS3, the model converged at the seventh iteration, which leads to the results shown in Figure and in **Błąd! Nie można odnaleźć źródła odwołania.**. When the five constructs explained by BCT are examined, it becomes clear that all five constructs show strong relationships. Path coefficients are between 0.446 and 0.617, R^2 between 0.192 and 0.375, and all relationships are significant with *p*-values lower than 0.01. When the construct of SCP is examined, it becomes clear that its variance is explained with an R^2 of 0.675 by its five predicting constructs, with product traceability having the strongest relationship with a path coefficient of 0.234. The *p*-values, indicating the levels of statistical significance, are between 0.019 and 0.097, indicating moderately to strongly significant relationships.

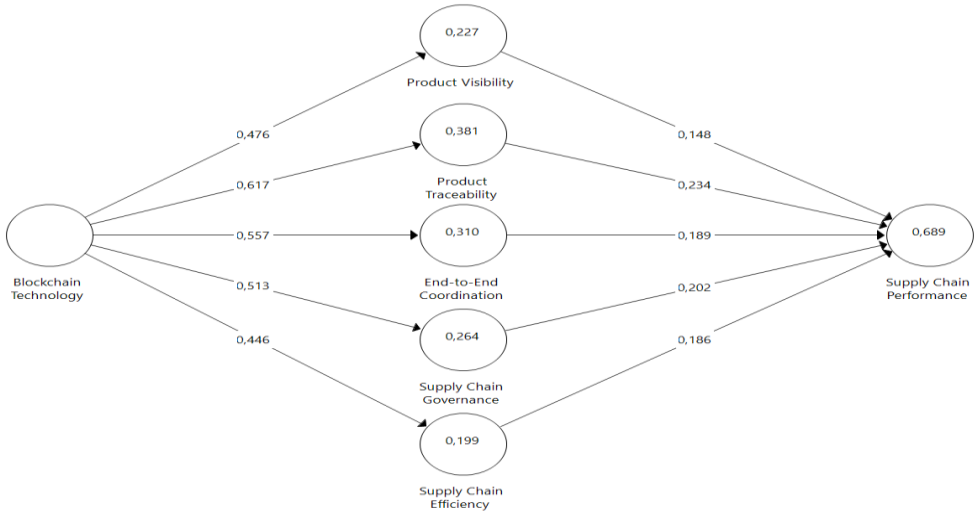
Table 5. HTMT criterion results

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
(1) Blockchain Technology						
(2) End-to-End Coordination	0.66					
(3) Product Traceability	0.72	0.88				
(4) Product Visibility	0.55	0.76	0.82			
(5) Supply Chain Efficiency	0.54	0.89	0.82	0.72		
(6) Supply Chain Governance	0.60	0.85	0.69	0.65	**0.91**	
(7) Supply Chain Performance	0.61	0.84	0.82	0.74	0.83	0.78

Source: authors' own research

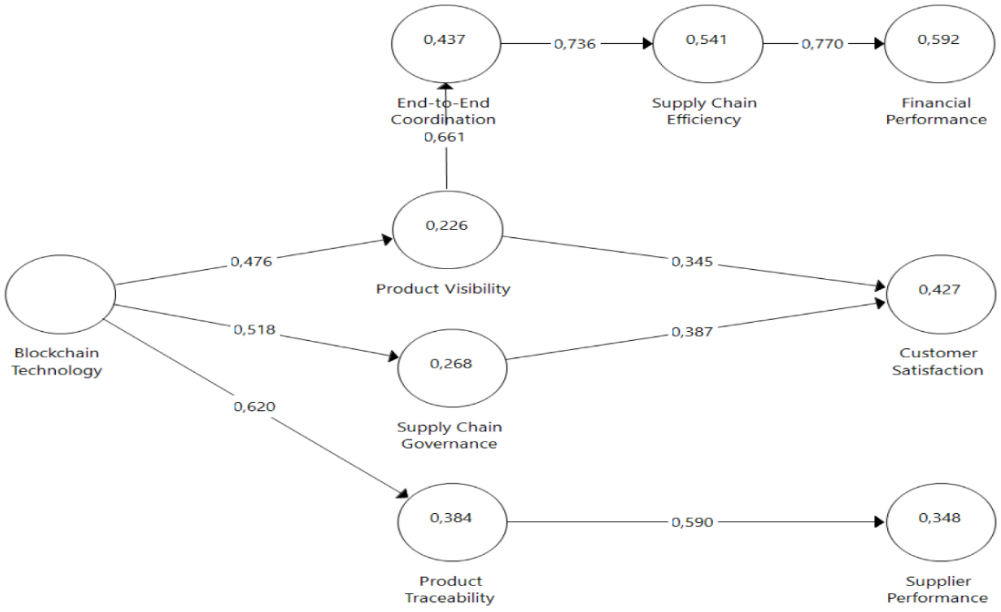
As discussed in the literature review, SCP can be constructed from supplier performance, customer satisfaction, and financial performance, and the five constructs can thus be tested on these three constructs of SCP individually. This model was constructed and loaded into SmartPLS. Figure 3 shows our final empirically validated model.

Figure 2. Research model results



Source: authors' own research

Figure 3. Final research model



Source: authors' own research

6. Conclusions and discussion

Continuous outsourcing and specialisation within organisations have increased the emphasis on cost reduction and have therefore led to the increased need to optimize their competitiveness and performance. The use of blockchain technology is a promising way to improve supply chain performance. In this study, we found significant effects of the BCT use on product visibility, product traceability, end-to-end coordination, supply chain governance, and supply chain efficiency. In addition, these factors positively impacted the supply chain performance. Finally, when SCP is separated into supplier performance, customer satisfaction, and financial performance, this research has concluded that product visibility and supplier governance are strong and significant drivers of customer satisfaction, that product traceability is a strong and significant driver of supplier performance, and that end-to-end coordination and supply chain efficiency are strong and significant drivers of financial performance.

6.1 Positive effects of BCT

The results of this research indicate that, as was hypothesised, the use of BCT can lead to improved visibility and traceability of products in a supply chain. Traceability was also found to have a strong effect on supply chain performance, which is in line with the experience of many organisations. For example, the large American retail chain Walmart has claimed that product traceability of their mangoes, all the way back to their source, improved from 7 days to a mere 2.2 seconds (HyperLedger 2018) after implementing IBM's Hyper Ledger. Hyper Ledger is a blockchain fork that uses BCT specifically to improve the traceability of products (HyperLedger 2021).

End-to-end coordination (E2E coordination) is the integration of all flows of information, goods, or money within an organisation or within a supply chain. End-to-end coordination is believed to benefit from the use of BCT from the increased visibility of all nodes in the supply network and, as a result, trust can be established between different entities within the network that might not be familiar with each other. Unfamiliar entities may be hesitant to share information in fear of undermining each other's business (Sharma 2020). BCT can enable the sharing of information in a

safe way and on a predetermined basis, even on a case-to-case basis if desired. The results of this study indicate that the use of BCT may lead to improved E2E coordination, which in its turn also has a positive effect on supply chain performance.

The use of BCT in a supply chain stimulates data availability, visibility, security, and benefits from using common language and terminology (Casado-Varaa et al. 2018). Because of the inherent nature of BCT, the data surrounding the terms and execution of the contract are visible for all predetermined users and parties involved with the smart contract. It is therefore often argued that organisations can – through the use of smart contracts – improve the governance and efficiency of their supply chains (Hald, Kinra 2019). We found that the use of BCT is indeed able to improve the governance and efficiency in supply chains. Supply chain governance and efficiency both have a positive effect on SCP as well. Interestingly, when the effect of supply chain efficiency on financial SCP is studied, SC efficiency has a very strong and statistically significant effect. This may be because in an efficient supply chain few resources are wasted, which would lead to a better financially performing supply chain.

6.2 Impact on supply chain performance

The results show particularly strong and significant effects of product traceability and SC governance on supply chain performance and moderately strong effects of the other three constructs on SC performance. To be able to put this into a more practical context, we need to zoom in on exactly which parts of a supply chain these performance gains find their origin in. If we look at customer satisfaction, then the results suggest that increased product visibility and SC governance are the strongest drivers. In the case of product visibility, the reasons for this might be found in the growing tendency (MAI-Solutions 2020) – not necessarily limited to BCT – of organisations to display current inventory levels on E-commerce websites, showing the phase of production that a made-to-order product is in, or even the live location of food ordered from a delivery restaurant. This could lead to higher levels of customer satisfaction. In the case of SC governance, the effect is harder to understand. Supply chains with higher levels of governance may be in better control of the nodes within the network, which in turn can lead to better and more concise communication

towards customers, shorter lead times, and possibly even lower costs. More elaborate research would have to be designed and executed in order to fully understand the underlying drivers of supply chain governance on SCP.

We found that the strongest driver for supplier performance in our study was product traceability. As several publications suggest (Xu et al. 2019; Lu, Xu 2017; Dabbene, Gay 2011) to have traceability of products, especially if this traceability finds its origins in BCT, strong relationships and partnerships need to be built and formed between organisations and their suppliers. Even if just one of the suppliers of an organisation does not incorporate BCT in their part of the supply chain, the traceability of the products is – at least partly – lost, and full traceability cannot be achieved. Organisations that managed to have very good traceability of their products are therefore expected – through the requirement of BCT-induced traceability itself – to show strong supplier performance as well. Because having product traceability thus relies strongly on the extent to which organisations and their suppliers are willing to cooperate, the increased performance in suppliers that is witnessed will most likely not even be a direct result of using BCT but merely an interesting side effect.

Finally, in the case of the financial performance of a supply chain, two drivers stand out: end-to-end coordination and supply chain efficiency. For the latter driver, this might not be hard to understand. An efficient supply chain wastes few resources, and if there is little waste in terms of manpower, machinery, or money, higher financial performance can be expected. End-to-end coordination, in contrast, is a more interesting driver of financial performance, even though the effect it has is less strong. Obviously, product visibility facilitates and improves end-to-end coordination, which can in turn positively impact supply chain efficiency and financial SC performance. Apparently, if products are more visible to all responsible stakeholders in a supply chain, the coordination through the whole supply chain can and will improve. Actors in the supply chain are in turn believed to use this information to make better decisions that will in turn improve the efficiency of a supply chain as well. This will eventually lead to better financial results.

6.3 Recommendations for practitioners

One might easily question the usefulness of new technologies such as blockchain technology. The results of this study appear to confirm the merits and positive effects of BCT use. Companies should acknowledge the impact of blockchain technology use on product visibility and traceability, E2E coordination, and supply chain governance and efficiency. Implementing and using BCT is likely to foster improvement in a wide range of performance indicators. The strongest effect of BCT appears to be on product traceability which is directly related to the financial performance of supply chains. Organisations that are interested in improving their supplier and financial performance and are willing to invest in implementing new technologies could look at BCT as a serious driver for these two SC performance aspects.

6.4 Limitations and recommendations for research

The geographical location of an organisation might – due to geopolitical reasons – influence both the likelihood of implementing and using BC and the effects that using this technology might have. The conclusions and results of this study should be evaluated in the context of the research method. Since the study only included companies from North America, the results cannot without hesitation be generalized to companies in other countries and regions. If this study would have been replicated in a broader, more global setting, the researchers should account for possible biases due to geopolitical differences which might alter some of the results of our study. Future studies could include the geographical location of organisations as a control variable in the conceptual model. In addition, future studies should try to enlarge the number of respondents. The response was, after removing the entries with more than 15% missing data, 112. We encountered two validity issues. The first issue is that the CA value for the construct of supply chain efficiency is 0.68, while most literature points at 0.70 being the lower threshold to expect strong internal validity. The second issue is that of discriminant validity. An HTMT, Monte Carlo-based analysis was performed between all reflective constructs, resulting in an HTMT value of 0.91 between supply chain efficiency and supply chain governance, while common literature generally considers two reflective constructs to be valid from 0.90 or lower.

Even though both thresholds, that of CA and that of HTMT, are breached by a minimal amount, future studies could be designed to overcome these issues.

In this study, different types of DLT have been aggregated into 'BCT'. In reality, many different types, versions, varieties, and forks of blockchain exist, and they all have their own strong and weak points. Several forks of blockchain, for example, have been created specifically to enhance product visibility and traceability. Others, however, have focussed mainly on the implementation and use of smart contract, to enhance transactional efficiency and governance. Some technologies have even specifically been developed to make life hard on producers of counterfeit products. It is clear that because all technologies have different use cases, their effect on supply chain performance might differ along with them. Future studies could investigate and include the nuances within different forks of BCT. This study focusses on the benefits of BCT use. Future studies could investigate the negative impacts and side-effects of BCT, such as issues related to inefficiencies/cost, regulatory uncertainties, privacy, and (resource) dependencies.

References

Abeyratne S., Monfared R. (2016), Blockchain Ready Manufacturing Supply Chain Using Distributed Ledger, Loughborough University Institutional Repository.

Alicke K., Benavides L., Sankur A. (2017), Three game-changing supply chain technologies, McKinsey&Company: Operations Extranet, https://www.mckinsey.com/capabilities/operations/our-insights/three-game-changing-supply-chain-technologies [17.09.2022].

Alicke K., Rachor J., Seyfert A. (2019), Supply chain 4.0 – the next-generation digital supply chain, McKinsey&Company, Supply Chain Management, https://www.industr.com/en/supply-chain-the-next-generation-digital-supply-chain-2465291 [17.09.2022].

Al-Shboul M.A.R. et al. (2017), The effect of supply chain management practices on supply chain and manufacturing firms' performance, "Journal of Manufacturing Technology Management", vol. 28 no. 5, pp. 577–609.

Banker S. (2017), Blockchain in the supply chain: too much hype, Forbes, https://www.forbes.com/sites/stevebanker/2017/09/01/blockchain-in-the-supply-chain-too-much-hype/?sh=5474e9fd198c [22.01.2021].

Beamon B.M. (1999), Measuring supply chain performance, "International Journal of Operations & Production Management", vol. 19 no. 3, pp. 275–292.

Becker J., Kahn D. (2003), The process in focus, in: Process management, Becker J., Kugeler M., Rosemann M. (eds.), Springer, Berlin, Heidelberg, pp. 1–12.

Benton W., Prahinskia C., Fan Y. (2020), The influence of supplier development programs on supplier performance, "International Journal of Production Economics", vol. 230, art. 107793.

Buer T., Haasis H.-D., Kinra A., Kotzab H. (2019), An overview to contemporary maritime logistics and supply chain management decision areas, in: Routledge Handbook of Maritime Management, Routledge, London.

Burnette M., Dittmann P. (2018), UT's Haslam college of business, https://haslam.utk.edu/sites/default/files/E2E_Collaboration_0.pdf [29.01.2021].

Casado-Varaa R., Prieto J., De la Prieta F., Corchadoa J.M. (2018), How blockchain improves the supply chain. Case study alimentary supply chain, "Procedia Computer Science", no. 134 , p. 393–398.

Cengiz E. (2010), Measuring customer satisfaction: must or not?, "Journal of Naval Science and Engineering", vol. 6 no. 2, pp. 76–88.

Chan F.T. S., Qi, H. (2003), An innovative performance measurement method for supply chain management, "Supply Chain Management", vol. 8 no. 3, pp. 209–223.

Chang W.-S., Lin Y.-T. (2019), The effect of lead-time on supply chain resilience performance, "Asia Pacific Management Review", vol. 24 no. 4, pp. 298–309.

Cong L.W., He Z. (2019), Blockchain disruption and smart contracts, "The Review of Financial Studies", vol. 32 no. 5, pp. 1754–1797.

Dabbene F., Gay P. (2011), Food traceability systems. Performance evaluation and optimization, "Computers and Electronics in Agriculture", vol. 75 no. 1, pp. 139–146.

Dabbene F., Gay P., Tortia C. (2014), Traceability issues in food supply chain management: a review, "Biosystems Engineering", vol. 120, pp. 65–80.

Dickson B. (2016), Blockchain has the potential to revolutionize the supply chain, https://techcrunch.com/ [01.01.2021].

European Commission (2007), Food traceability, https://ec.europa.eu/f [25.01.2021].

Falazi G., Hahn M., Breitenbücher U., Leymann F. (2019), Modeling and execution of blockchain-aware business processes, "SICS Software-Intensive Cyber-Physical Systems", vol. 34, no. 2/3, pp. 105–116.

Fornell C., Larcker D.F. (1981), Evaluating structural equation models with unobservable variables and measurement error, "Journal of Marketing Research", vol. 18 no. 1, pp. 39–50.

Gaehtgens F., Allan A. (2017), Digital trust – redefining trust for the digital era, https://www.gartner.com/ [01.01.2021].

GICS (2020), Global industry classification standard, https://www.msci.com/gics [01.01.2021].

Gunasekaran A., Patel C., Tirtiroglu E. (2001), Performance measures and metrics in a supply chain environment, "International Journal of Operations & Production Management", vol. 21, no. 1/2, pp. 71–87.

Hackius N., Petersen M. (2017), Blockchain in logistics and SCM: trick or treat, in: Digitalization in supply chain management and logistics. Smart and digital solutions for an industry 4.0 environment. Proceedings of the Hamburg International Conference of Logistics (HICL), Vol. 23, Kersten W.B., Ringle T., Christian M. (eds.), epubli, Berlin, pp. 3–18.

Hair J.F. et al. (2006), Multivariate data analysis, 6th ed., Pearson Education International, New York.

Hald K.S., Kinra A. (2019), How the blockchain enables and constrains supply chain performance, "International Journal of Physical Distribution & Logistics Management", vol. 49 no. 4, pp. 376–397.

Hanan M., Karp P. (1989), Customer satisfaction: how to maximize, measure, and market your company's ultimate product, 12th ed., American Management Association, New York.

Handfield R.B., Nichols E.L. (2015), Introduction to supply chain management, Pearson Education, Noida.

Henseler J., Ringle C.M., Sarstedt M. (2015), A new criterion for assessing discriminant validity in variance-based structural equation modelling, "Journal of the Academy of Marketing Science", vol. 43 no. 1, pp. 115–135.

Hill J., Thomas A. J., Mason-Jones R.K., El-Kateb S. (2018), The implementation of a Lean Six Sigma framework to enhance operational performance in an MRO facility, "An Open Access Journal", vol. 6 no. 1, pp. 26–48.

Hyperledger (2018), https://www.hyperledger.org/ [08.04.2021].

Iansiti M., Lakhani K.R. (2017), The truth about blockchain, "Harvard Business Review", https://hbr.org/2017/01/the-truth-about-blockchain [17.09.2022].

Inman R.A., Green K.W. (2018), Lean and green combine to impact environmental and operational performance, "International Journal of Production Research", vol. 56 no. 11, pp. 4802–4818.

Ishtiaque S., Siddiqui D.A., Ahmed W. (2020), Impact of technology-based integrated responsive supply chain on operational performance: a case of a volatile market, "International Journal of Logistics Systems and Management", vol. 35 no. 3.

Jöreskog K.G., Wold H. (1982), Systems under indirect observation, Part I. Amsterdam: s.n.
Kamble, S., Gunasekaran, A. & Arha, H., 2018. Understanding the Blockchain technology adoption in supply chains-Indian context. International Journal of Production Research.

Kersten W. et al. (2017), Trends and strategies in logistics and supply chain management: digital transformation opportunities, DVV Media, Hamburg.

Kooij D., Boon C. (2018), Perceptions of HR practices, person–organisation fit, and affective commitment. The moderating role of career stage, "Human Resource Management Journal", vol. 28 no. 1, pp. 61–75.

Kshetri N. (2018), Blockchain's roles in meeting key supply chain management objectives, "International Journal of Information Management", vol. 39, pp. 80–89.

Kull T., Yan T., Liu Z., Wacker J. (2014), The moderation of lean manufacturing effectiveness by dimensions of national culture: testing practice-culture congruence hypotheses, "International Journal of Production Economics", vol. 153, pp. 1–12.

Laurent J., Leicht R.M. (2019), Practices for designing cross-functional teams for integrated project delivery, "Journal of Construction Engineering and Management", vol. 145 no. 3, https://ascelibrary.org/doi/10.1061/%28ASCE%29CO.1943-7862.0001605 [18.09.2022].

Li S., Nathan R., Ragu-Nathan T.S., Rao S. (2006), The impact of supply chain management practices on competitive advantage and organisational performance, "The International Journal of Management Science", vol. 34, pp. 107–124.

Lu Q., Xu X. (2017), Adaptable blockchain-based systems: a case study for product traceability, "IEEE Software", vol. 34 no. 6, pp. 21–27.

MAI-Solutions (2020), http://www.mktalt.com/ [09.04.2021].

Mani V., Gunasekaran A., Delgado C.J.M. (2018), Enhancing supply chain performance through supplier social sustainability: an emerging economy perspective, "International Journal of Production Economics", vol. 195, pp. 259–272.

McColl-Kennedy J., Schneider U. (2010), Measuring customer satisfaction: why, what and how, "Total Quality Management", vol. 11 no. 7, pp. 883–896.

McCormack K., Ladeira M.B., de Oliveira M.P.V. (2008), Supply chain maturity and performance in Brazil, "Supply Chain Management: An International Journal", vol. 13 no. 4, p. 272–282.

Miri-Lavassani K., Movahedi B. (2018), Achieving higher supply chain performance via business process orientation, "Business Process Management Journal", vol. 24 no. 3, pp. 671–694.

Nakamoto S. (2008), Bitcoin: a peer-to-peer electronic cash system, https://bitcoin.org/bitcoin.pdf [01.01.2021].

Nandi M.L., Nandi S., Moya H., Kaynak H. (2020), Blockchain technology-enabled supply chain systems and supply chain performance: a resource-based view, "Supply Chain Management: An International Journal", vol. 25 no. 6, pp. 841–862.

Nowiński W., Kozma M. (2017), How can blockchain technology disrupt the existing business models?, "Entrepreneurial Business and Economics Review", vol. 5 no. 3, pp. 173–188.

Ølnes S., Ubacht J., Janssen M. (2017), Blockchain in government: benefits and implications of distributed ledger technology for information sharing, "Government Information Quarterly", vol. 34 no. 3, pp. 355–364.

O'Marah K. (2017), Blockchain for supply chain: enormous potential down the road, https://www.forbes.com/sites/ [01.01.2021].

Petersen M., Hackius N., See B. (2017), Mapping the sea of opportunities: blockchain in supply chain and logistics, "IT – Information Technology", vol. 60 no. 5–6, pp. 263–271.

Podsakoff P., MacKenzie S., Lee J.-Y., Podsakoff N.P. (2003), Common method biases in behavioural research: a critical review of the literature and recommended remedies, "Journal of Applied Psychology", vol. 88 no. 5, pp. 879–903.

Salah S., Rahim A. (2018), An integrated company-wide management system, Springer.

Seebacher S., Schüritz R. (2017), Blockchain technology as an enabler of service systems: a structured literature review, "IESS", 24 May, pp. 12–23.

Sharma T.K. (2020), Blockchain Council, https://www.blockchain-council.org/ [08.04.2021].

Sharples M.D.J. (2016), The blockchain and kudos: a distributed system for educational record, reputation and reward, in: Adaptive and Adaptable Learning: 11th European Conference on Technology Enhanced Learning, Verbert K., Sharples M., Klobučar T. (eds.), Springer International Publishing, Cham.

Smart A., Bunduchi R., Gerst M.H. (2010), The costs of adoption of RFID technologies in supply networks, "International Journal of Operations & Production Management", vol. 30 no. 4, pp. 423–447.

Söderberg L., Bengtsson L. (2010). Supply chain management maturity and performance in SMEs, "Operations Management Research", vol. 3 no. 1, pp. 90–97.

Szabo N. (1996), Smart contracts: building blocks for digital markets, http://www.truevaluemetrics.org/ [29.01.2021].

Tapscott D., Tapscott A. (2018), Blockchain revolution: how the technology behind Bitcoin and other cryptocurrencies is changing the world, Portfolio, London.

Tjahjono B., Esplugues C., Ares E., Pelaez G. (2017). What does industry 4.0 mean to supply chain, "Procedia Manufacturing", vol. 13, pp. 1175–1182.

Tortorella G.L., Giglio R., Limon-Romero J. (2018), Supply chain performance: how lean practices efficiently drive improvements, "Journal of Manufacturing Technology Management", vol. 29 no. 5, pp. 829–845.

Tortorella G., Miorando R., Tlap D. (2017), Implementation of lean supply chain: an empirical research on the effect of context, "The TQM Journal", vol. 29 no. 4, pp. 610–623.

Treiblmaier H. (2018), The impact of the blockchain on the supply chain: a theory-based research framework and a call for action, "Supply Chain Management: An International Journal", vol. 22 no. 6, pp. 486–505.

Umble E.J., Haft R.R., Umble M.M. (2003), Enterprise resource planning: implementation procedures and critical success factors, "European Journal of Operational Research", vol. 146 no. 2, p. 241–257.

Underwood S. (2016), Blockchain beyond Bitcoin, "Communications of the ACM", vol. 59 no. 11, pp. 15–17.

United Nations (2014), A guide to traceability: a practical approach to advance sustainability in global supply chains, https://d306pr3pise04h.cloudfront.net/docs/issues_doc%2Fsupply_chain%2FTraceability%2FGuide_to_Traceability.pdf [31.01.2021].

Vo B., Kongar E., Barraza M.F.S. (2019), Kaizen event approach: a case study in the packaging industry, "International Journal of Productivity and Performance Management", vol. 68 no. 7, pp. 1343–1372.

Wang Y., Han J.H., Beynon-Davies P. (2018), Understanding blockchain technology for future supply chains: a systematic literature review and research agenda, "Supply Chain Management", vol. 24 no. 103.

Westerkamp M., Victor F., Küpper A. (2020), Tracing manufacturing processes using blockchain-based token compositions, "Digital Communications and Networks", vol. 6 no. 2, pp. 167–176.

Wonga L.-W. et al. (2019), Time to seize the digital evolution: adoption of blockchain in operations and supply chain management among Malaysian SMEs, "International Journal of Information Management", vol. 52, art. 101997.

Xu X. et al. (2019), Designing blockchain-based applications a case study for imported product traceability, "Future Generation Computer Systems", vol. 92, pp. 399–406.

Yang F., Zhang X. (2017), The impact of sustainable supplier management practices on buyer-supplier performance: an empirical study in China, "Review of International Business and Strategy", vol. 27 no. 1, pp. 112–132.

Yu W. et al. (2017), Data-driven supply chain capabilities and performance: a resource-based view, "Transportation Research Part E: Logistics and Transportation Review", vol. 114, pp. 371–385.

CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

ISSN 2543-9472; eISSN 2544-0365

Vol. 6, No.3, September 2022, 33-45

www.cerem-review.eu
www.ojs.wsb.wroclaw.pl

Energy storage

Les DUCKERS

Loughborough University of Technology, UK

Received: 16.08.2022, Revised: 31.08.2022, Revised: 20.09.2022, Accepted: 23.09.2022
doi: https://dx.doi.org/10.29015/cerem.958

Aim: The aim of this paper is to explore Energy Storage requirements and options to suit the needs of systems and transport fed from renewables. The variability of wind and solar sources in particular and the demand for transport energy are seen as key issues.

Design / Research methods: The paper outlines the need for energy storage and compares the energy density and power density of a selection of storage options.

Conclusions / findings: The results illustrate the difficulties of finding storage mechanisms to rival fossil fuels in both energy density and power density. Moreover finding the natural resources to provide sufficient storage will be a serious challenge even though the economic costs of storage systems are falling..
Originality / value of the article: The article demonstrates the importance of energy storage to the successful development of renewable energy systems, and of the economic and physical characteristics that such energy storage schemes should have.

Implications of the research: Energy storage as a topic should be given a high priority for research and development.

Limitations of the research: This article is not comprehensive and a review of best practice internationally would be a valuable extension to this work.

Key words: *: Renewable energy, Energy Storage, Climate Change.*

JEL: Q42

Correspondence address: Les DUCKERS, Loughborough University of Technology, UK E-mail: les.duckers@yahoo.com.

1. Introduction

The transition from fossil fuels to renewables will require considerable investment in energy storage to deal with the intermittent nature of many of the renewable energy sources, and to ensure energy security. In this paper the importance of storage and the range of storage options is explored. Although the cost of storage is falling, limitations in storage solutions are shown to be extremely important, making it urgent to find much more energy storage.

Fossil fuels (coal, oil and gas) were essential to the growth of economies from the dawn of the industrial revolution to the end of the 20th century. Their high energy density, typically 10 000 Wh/kg (see Figure 2 for the data, see also Houghton 2009) means that they can readily be transported across large distances without using too much of the energy that they contain. For example a heavy goods vehicle (lorry or truck) could transport 30 000 kg of oil with emissions of CO_2 from burning diesel. The same journey to transport wood chips would consume the same quantity of diesel and emit the same amount of CO_2 but would only deliver about half the energy. This is due to the lower energy content or energy density of wood compared to oil and helps to explain the vital part that fossil fuels have played in the development of economies.

A typical car running on diesel has a large range of 750 km because the energy density of the 50 kg of diesel in the fuel tank is 12 900 Wh/kg. (see Figure 2 for data on energy densities, the fuel economy is based on UK Government data, 2022). If we replace the fuel tank with lead acid batteries, of the type found in all conventional internal combustion cars, then we would require 16 tonnes of batteries. This is clearly impossible in a car which only has a mass of 2 tonnes. The range of such an electric car would be restricted by the amount of batteries and the energy storage density of those batteries (around 40 Wh/kg). Of course the present generation of electric vehicles use advanced Li-ion batteries with greater energy storage density of around 160 Wh/kg and we will return to this later.

The attraction of fossil fuels is their energy density and ease of transport and storage. The geographical locations where substantial fossil fuels are found have prospered or have been subjugated by large companies or colonial powers. The control

of fossil fuel supplies is very much a geopolitical issue (see Yergin 1991, 2021; Marshal 2015). That control is in a few hands and, as the current Ukrainian invasion shows, the impact of restricting flow of resources can be immense. Russia controls a significant fraction (around 40%) of the gas supply to Europe which will create severe difficulties for many European states particularly as the 2022/3 winter approaches and gas for heating is limited and/or expensive. See for example Reuters Business (2022).

There are two technical problems that arise from our exploitation of fossil fuels. The first is that of global resource: The BP annual review (2021) reports the ratio of resource to production for oil and gas at around 50 years. Each year these ratios remain at about the same level because as consumption reduces the resource so exploration, in ever more inaccessible remote locations such as deep water oceans, identifies more resource. Geologists recognize that there will be an ultimate resource limit: i.e. that total amount which was produced in geological time. It is fair to say that fossil fuel resources can only last a few decades and certainly not sustain our grandchildren.

Geopolitical tensions over the world's fossil fuel resources are already in play and perhaps they always were (Yergin 1991, 2021). The Arctic is one area where Russia, US, Canada, Denmark, Iceland and Norway are claiming territory. China has interests all over the World, including Greenland where climate change is reducing ice cover and revealing precious mineral resources. There is an internationally agreed embargo on exploitation of the Antarctic, but the strength of the agreement is as yet untested.

The second technical problem with fossil fuels is that burning them enhances the greenhouse effect and leads to climate change. This has been understood for some years and had drawn commitments from many countries at many conferences to restrict greenhouse gas emissions (principally from burning fossil fuels). Unfortunately none of these commitments has ever been fully met, and we are now in a climate emergency: probably posing the greatest ever risk to humanity. The November 2022 meeting of COP27 in Egypt must promote rapid progress needed to reach "zero carbon" to avoid transiting the tipping point of a global temperature rise of 1.5 or 2 ºC above pre-industrial levels.

2. Renewables and their storage

2.1. Solar energy

To replace fossil fuels, renewable energy in various forms has been investigated and a number of these have been taken through to deployment. Renewables are so called because they are “renewed” usually daily from the Sun. Solar energy can be converted to thermal energy, or to electricity or through photosynthesis to biomass. Tunisia, for example is deploying large areas of photovoltaic (PV) collectors (IRENA 2022). A proposed scheme to deploy vast arrays of PV collectors across North Africa to feed electricity into Europe was thwarted by the Arab Spring of 2010 which created nervousness in investors.

Solar panels produce direct current (dc) electricity which can be stored in batteries to meet demand on cloudy days or through the night. Integrating PV into a grid entails passing the dc electricity through an inverter to produce alternating current (ac) electricity. This ac electricity cannot be stored and so the PV owner must export surplus/import deficit from the grid.

Solar thermal collectors produce hot water which can easily be stored in a large drum at a domestic level as is common in Mediterranean countries. Hot water can be stored for a day or two, however storing enough energy during the summer to give winter space heating would require a much larger capacity container capable of storing heat efficiently over several months. The likely winter demand is almost certain to be several months behind the solar peak.

Some recent reports (Polar Night Heating 2022) of using sand rather than water as the storage medium are encouraging. Sand has a higher thermal capacity than water when heated to over 500 ºC, whereas water can only be heated to around 80 ºC .

2.2. Wind energy

Wind is created by weather patterns on the Earth, and is thus a result of solar insolation. Modern wind turbines produce electricity at competitive rates, and in many cases at lower cost than all other forms of energy (Lazard 2022). Many countries already have large wind farms feeding into their grids, and together with hydro and PV, renewables contributed 13% of total power generation (BP 2022; the report does

not show resource to production rations, see previous years report), with China making up 36% and 40% respectively of world PV and wind. Oersted is developing the world's largest wind project, Hornsea Two in the North Sea with a capacity of 1.3 GW, from the deployment of 165 8 MW turbines. The next phase, Hornsea Three, will be rated at 2.8 GW.

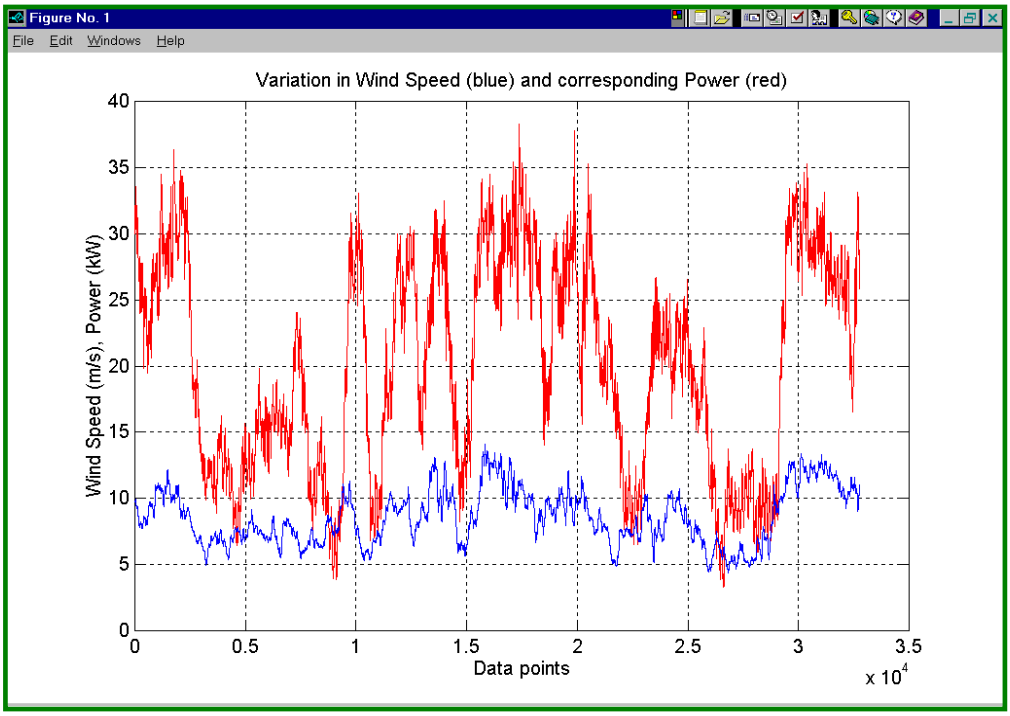
The intermittent nature of wind means that energy storage or an alternative source such as gas will be needed to meet demand during calm periods. This may mean storing energy for a day or two. The cost of energy storage is falling quickly (see Lazard 2022). Employing an additional source like a standby diesel generator also places economic strain on the scheme as there are addition investment costs as well as fuel costs. A shorter-term storage problem for wind turbines arises from the unsteady nature of the wind resource. Instead of blowing with a constant velocity, wind is prone to blow in gusts. Figure 1 shows the variation in wind velocity (V) over a few minutes as the lower trace. The electrical output from a wind turbine, which is loosely related to V^3, is the upper trace. This output must be smoothed before delivery to a consumer. In the case of large arrays there will be statistical smoothing, but small numbers of turbines will require energy storage over a few minutes to accomplish a steady output. Thus a single turbine or a collection of a few turbines might require battery storage.

2.3. Hydroelectricity

Hydroelectricity comes from solar induced weather. Most countries have constructed dams for flood control, water supply or power generation (or all of these). These dams schemes already contribute about 4500 TWh or 16% to world electrical supplies (BP 2022), but suffer from periods of low rainfall. This situation is increasingly concerning as more frequent episodes of extreme weather conditions are predicted as a consequence of climate change.

In terms of energy storage, though, dam schemes are ideal. The water held in the reservoir behind the dam is effectively "stored energy" which can be released to meet demand. The Itaipu dam shared by Brazil and Paraguay (completed in 1984) is the second largest in the world and serves Brazil and Paraguay with 14 GW of electrical power (Itaipu Binacional 2022).

Figure 1. Variation in wind velocity (lower trace) and associated power (upper trace) over a few minutes



Source: author's elaboration.

The Foyers hydro-electrical scheme built on the side of Loch Ness in Scotland has a much smaller capacity but does have an additional feature: it is a pump storage scheme (Foyers Hydro Scheme 2022). During times of surplus electricity on the grid its two Francis turbines are run as pumps and together pump 320 m^3/s of water up to Loch Mhor which is 179 m vertically above Loch Ness. When demand on the grid rises this water is released through the turbines back to Loch Ness. Loch Ness is linked to the sea and so is not vulnerable in times of low rainfall. The turbines each generate 150 MW into the grid. This scheme is quite small, and together with three other schemes have a combined storage capacity of around 2% of the average daily electricity supplied by the UK grid, the stored energy helps to smooth the supply/demand curve on the UK grid but is too small to offer energy security.

A second type of hydro-electric scheme is "run of river", which generally have no water storage. They are based on historical water mills, which were common

throughout Europe 2000 years ago, and sometimes included a mill pond to collect water over a few days until there was sufficient water to drive the wheel and grind corn or other mechanical tasks. An example of a modern run of river scheme is Niagara Falls shared by US and Canada. In fact this is an unusual run of river scheme in that the falls that tourists experience during the day means that the energy is lost as water crashing over the falls. At night the falls become quiet as the authorities divert the water to a reservoir where it is stored overnight to provide electrical generation the next day. Most run of river schemes do not store water as potential energy.

2.4. Biomass

Biomass is produced through photosynthesis by captured solar energy. In terms of energy storage most forms of biomass mimic fossil fuels as they can readily be stored, transported and burned, although they are generally less energy dense.

2.5. Wave energy

Ocean waves result from the transmission of wind energy into water. Strong winds blowing across long fetches of ocean for many hours will generate large waves with associated high power densities. We can regard waves as a concentrated form of wind (and therefore solar energy). The west coast of Europe is subjected some of the most energetic wave climates in the World, and concepts to harness this resource have been envisaged for 200 years. Developments over recent decades are leading towards first generation schemes. The variation of height and period of waves makes them appear random and unpredictable and so exploiting this potential resource will demand suitable storage to be able to match supply to demand.

2.6. Tidal energy

Tidal ranges can reach 10 m or more in some locations of the World. Since the tides are produced by gravitational attraction and spinning of the Earth-Moon and Earth-Sun systems they are highly predictable, but occur on a 12h 25 m cycle so that the time of the peak tide is changing each day. Exploiting these large tides can be done by means of a barrage, such as the one at La Rance in France, which has been operational since 1969, or by the use of tidal stream technology. La Rance, and a

similar scale (of around 250 MW) barrage scheme at Sihwa in South Korea, have some inherent storage. The La Rance tidal scheme output provides 0.12% of France's electrical generation. The water flow can be controlled to some extent as it enters and/or leaves the barrage and so it is possible to match supply to demand to some degree, and offers a modest storage, with a small amount of pumped storage also being available by running the 24 Kaplan turbines as pumps at high tide to increase the height of water inside the barrage. The tidal stream technology on the other hand only operates in real time in tidal flow and so storage of energy must be done externally. A good example of this is at Bluemull on the Scottish island of Shetland. Here Nova have installed four 100 MW underwater turbines to generate electricity from the flow of the tide. To ensure a 24-hour supply of electricity to the community a Tesla battery bank stores energy during the generation phase and delivers energy during the dwell phase of the tide (RenewableUK 2022).

3. Transport

Sustainable transport is a problem because of the need to carry a store of energy in the vehicle, and as pointed out earlier most renewables do not have the energy density of fossil fuels. Future developments must improve the energy density of renewables for use in transport. This section discusses some issues of storage of renewables for transport purposes.

Road: Lead acid batteries have poor energy storage density which renders them too heavy for modern electrical vehicles: in that the range is severely restricted. Alternative batteries such as Li-ion have superior storage density at 160 Wh/kg and so are already installed in electric cars. Electric lorries and buses are being developed. See Volvo (2022) for example.

Aviation: Aviation is a difficult problem because minimising aircraft mass limits the number of batteries on board and hence the range of the aircraft. Several airlines are experimenting with biofuels and expect to reach similar properties to fossil fuelled aircraft (CAPA 2021).

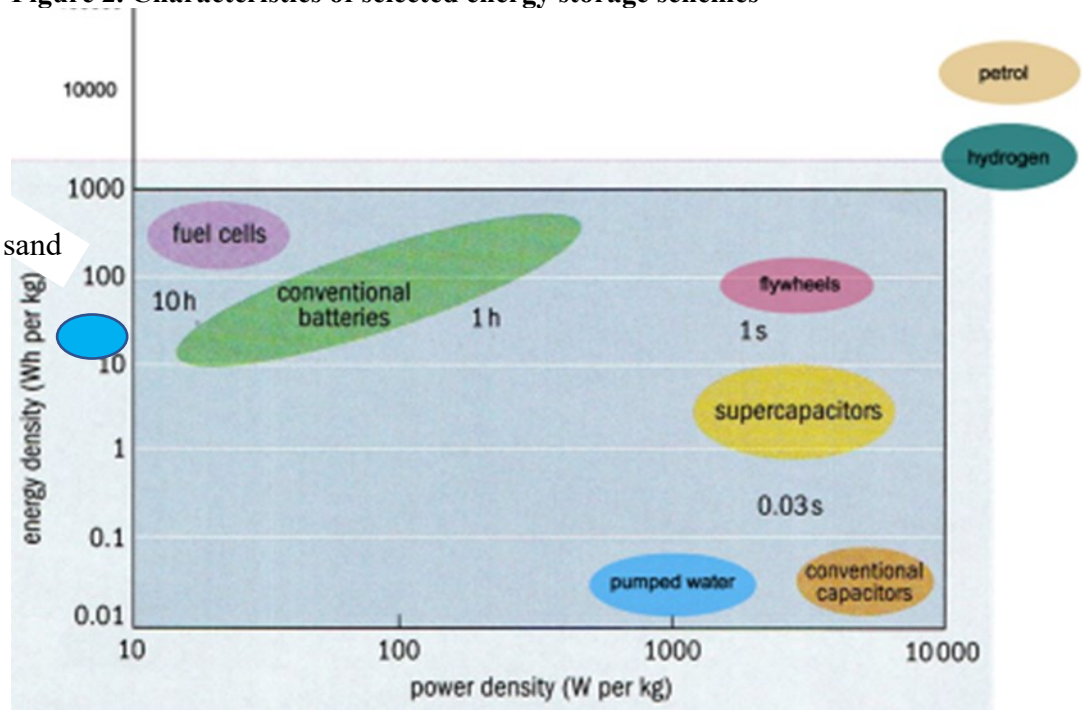
Sea: Following COP21 in Paris, world shipping is not required to make any progress towards zero carbon. The International Maritime Organization (IMO) negotiated this on behalf of its members, but it is not clear why COP26 or other meetings accepted this stance since international shipping is responsible for 3% of global carbon emissions. Meanwhile IMO (2021) has set out aspiration measures for its members. Maersk is planning to gradually convert its fleet to run on green methanol manufactured using renewables (Shippingwatch 2022).

4. Choice of storage

Figure 2 shows the technical characteristics of a select group of energy storage options. Selection of the best option depends on a number of factors such as mass, energy density and rate of energy delivery – that is the power density, which is plotted along the x axis. Note that pumped water is more power dense than batteries but is much less power dense than flywheels and capacitors and substantially less then hydrogen and petrol. In terms of energy density (how much energy can be stored) pumped water is very poor, meaning that pumped storage is not a particularly good option even for static storage. Again, petrol and hydrogen are the best, which reinforces the point made in the introduction that fossil fuels are very energy dense and flexible to use. Flywheels are interesting as a means to put braking energy into a store and then recover that energy later on. Formula 1 cars can obtain a short burst of additional power from this mechanism (Mercedes 2019). A sand energy store is undergoing trials in Finland, where 100 s of tonnes of sand are heated to 600 to 1000 ºC. This heat is retained efficiently (99% is claimed by Polar Night Heating [2022]) for several months and has potential to permit summer heat to be stored and used over the winter. Nominal output of 100 MW and capacity of 20 GWh would mean 200 hours of output at full power, 2000 hours at 10% power. They estimate the capital cost at less than €10/kWh. Plotting sand storage onto Figure 2 on the basis of data from the pilot project (100 tonnes of sand heated to 500 ºC, delivering 100 kW with a capacity of 8 MWh) suggests a good energy density, but a low power density. In the

context of space heating delivered over a long period at low power density this may be acceptable.

Figure 2. Characteristics of selected energy storage schemes



Source: Ragone diagram adapted from Houghton (2009) to included sand, hydrogen and petrol.

The energy density reflects the total energy stored in a kg of a scheme. How quickly that energy can be released is indicated by the "time" numbers which range from 0.03 s (and hence a high power density), to 10 h (a low power density).

Lead acid batteries contain about 30–40 Wh/kg whereas Li-ion batteries might hold 160 Wh/kg.

5. Cost of storage

Lazard (2022) give an annual review of Levelized Costs of Energy (LCOE) for all forms of energy, which includes energy storage. The costs for renewable energy have been falling for some years, due to improved performance and mass production, as have the costs for energy storage. In some aspects the renewables are extremely cost competitive, and investments in energy storage are bringing costs down. This all bodes well for the future, although BP review indicate that World fossil fuel gas consumption actually increased last year despite the obvious imperative to employ zero carbon technologies. Some of the explanation is the low capacity factor (that is low availability of renewable technologies, and the lack of sufficient storage to guarantee firm supply, or in the case of vehicles the apprehension (whether justified or not) about range. Investment in storage facilities will overcome these issues. Cost is unlikely to be a major impediment to providing firm power.

6. Limitations on energy storage

If cost and technical issues are overcome what are the concerns around the supply and storage of energy? One question is the ability to store enough energy to meet the needs of everyone. It is clear following the Russian invasion of Ukraine that most countries rely on real time supply of energy. At the moment sanctions against Russia and Russian gas from Siberia mean that Europe faces a shortage of gas. Some countries have attempted to store natural gas in depleted oil fields, and so provide a safety net of some months supply. The UK has some gas storage, but in March 2013 with heavy demand for gas heating found itself with only 6 hours supply left and the prospect of closing factories to ensure domestic heating could continue (Independent 2013). More recently, in July 2022, during adverse weather conditions, the UK had to purchase electricity from Belgium at a cost of €11500/GWh, whereas the normal price would be around €210/GWh (ITV 2022). A strategy of storing natural gas and electricity would clearly give more security of supply. As we move towards zero carbon such storage would have to be storage of electricity, heat and biofuels and that

is limited by available heat biofuel, and pump storage sites on a large scale, and by battery technology for smaller scale and vehicles. Mineral resources for battery storage are already under pressure. The price of Lithium carbonate increased by 58% in 2021, and by 400% in the first five months of 2022 to €54,000/tonne (BP 2022). The World resource of Lithium carbonate is finite and unless Lithium batteries can be almost fully recycled there will not be sufficient Li to provide batteries for all future electric vehicles.

7. Conclusion

Zero carbon energy is the only energy path to a sustainable future, but much of the renewable energy which could meet our needs will require an associated storage mechanism. Storage methods available to us are becoming more affordable, but they are often less energy dense and less power dense than the fossil fuels that they replace. Apart from these drawbacks there is often limited availability of sites for storage, or of resources to build them. A crude estimate suggests that we have only 1% of the energy storage capacity that we will ultimately require. An urgent programme of energy storage development and deployment is recommended, in parallel with stringent energy efficiency and conservation measures. Such measures will reduce the demand for energy and hence for energy storage. Last, but perhaps most importantly we should adopt SMART technology, SMART grids and SMART human behaviour.

References

BP (2021), Statistical review of world energy, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf [10.08.2022].

BP (2022). Statistical review of world energy (does not show resource to production rations, see previous years report), https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2022-full-report.pdf [10.08.2022].

IRENA (2022), Energy profile Tunisia, https://www.irena.org/IRENADocuments/Statistical_Profiles/Africa/Tunisia_Africa_RE_SP.pdf https://www.irena.org/.../Tunisia_Africa_RE_SP.pdf [18.09.2022].

CAPA (2021), Aviation Sustainability and the Environment, https://centreforaviation.com/analysis/reports/aviation-sustainability-and-the-environment-capa-15-jul-2021-568189 [16.09.2022].

Foyers Hydro Scheme (2022), Foyers Hydro Scheme, https://www.sserenewables.com/hydro/foyers [10.08.2022].

Hornsea 2 (2022), https://hornseaprojects.co.uk/hornsea-project-two [10.08.2022].

Houghton J. (2009), Global warming: the complete briefing, 4th ed., Cambridge University Press, London.

IMO (2021), MO at COP 26, https://www.imo.org/en/OurWork/Environment/Pages/IMO-at-COP-26.aspx [16.09.2022].

Independent (2013), https://www.independent.co.uk/news/uk/home-news/ [10.08.2022].

Itaipu Binacional (2022), https://www.itaipu.gov.br/en [10.08.2022].

ITV (2022), https://www.itv.com/news/london/2022-07-25/london [10.08.2022].

Lazard (2022), Levelized cost of energy, levelized cost of storage, and levelized cost of hydrogen, https://www.lazard.com/perspective/levelized-cost-of-energy-levelized-cost-of-storage-and-levelized-cost-of-hydrogen [10.08.2022].

Marshall T. (2015), Prisoners of geography. Ten maps that tell you everything you need to know about global politics, Elliott and Thompson, London.

Mercedes (2019), https://www.mercedesamgf1.com/en/news/2019/06/ [10.08.2022].

Polar Night Heating (2022), https://polarnightenergy.fi [10.08.2022].

RenewableUK (2022), https://www.renewableuk.com [10.08.2022].

Shippingwatch (2022), https://shippingwatch.com/carriers/article11719866.ece#:~:text=Maersk%20and%20BMW%20to%20develop%20ship%20fuel%20from,fuel%20types Maersk and BMW to develop ship fuel from alcohol, [16.09.2022].

Vehicle Certification Agency (2022), Find fuel consumption and emissions information on a new or used car (database), vehicle-certification-agency.gov.uk, [04.08.2022].

Volvo (2022), Electric Buses, https://www.volvobuses.com/en/city-and-intercity/innovation/electric-buses.html [16.09.2022].

Yergin D. (1991), The prize: the epic quest for oil, money and power, Free Press, New York.

Yergin D. (2021), The new map – energy, climate, and the clash of nations, Penguin Random House, London.

CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

ISSN 2543-9472; eISSN 2544-0365

Vol. 6, No.3, September 2022, 47-68

www.cerem-review.eu
www.ojs.wsb.wroclaw.pl

How do variations in dollar exchange rate impact food commodity prices in selected African countries?

David UMORU, Mishau AMEDU
Edo State University, Nigeria

Received: 06.08.2022, Revised: 01.09.2022, Revised: 08.09.2022, Accepted: 08.09.2022
doi: https://dx.doi.org/10.29015/cerem.955

Aim: Commodity exporting nations have significant terms of trade swings, making their actual exchange rate unstable. This study looked at how variations in dollar exchange rate affected food commodity prices in Africa between 1990 and 2021.

Design/Research methods: The study conducted GARCH analysis for ascertaining prevalence of volatilities of exchange rates and interest rates respectively in selected African countries. Also, we estimated both static and dynamic analysis driven by panel least squares and generalized method of moments (GMM) estimators on panel data from some commodity-exporting African, namely, Ghana, Gabon, Tunisia, Nigeria, and South Africa.

Findings: The dynamic GMM results reveal exchange rate and interest rate variations taken together had positive effects on commodity prices. GARCH estimates demonstrate significant volatility growth using both normal and t multivariate distributions. However, based on empirical findings, t-distribution had largest maximized log-likelihood of -8920.1 and also had a satisfactory df of 26.82 (<30). The results demonstrate that the Nigerian Naira had highest coefficient of volatility of approximately 71.2%. This was followed by the Ghanaian Cedi with a negative volatility rate of 71% and the South African rand with a coefficient of 65%. However, while all countries had negative volatility with respect to interest rate, all countries except Ghana had positive volatility in exchange rate of their currency. Ghana, Gabon, Tunisia, and Nigeria showed negative exchange rate volatility. A possible explanation for this high volatilities in the aforementioned countries is persistent domestic inflation.

Originality: The originality is rooted on establishment of food prices having some positive relation with pervasive exchange rate shocks. This is an indication of adverse effects of downward adjustment of exchange rate of local African currencies vis-à-vis the US dollar on food prices in the African countries covered in the study.

Correspondence address: David UMORU, Mishau AMEDU, Edo State University, Nigeria, E-Mail: david.umoru@yahoo.com; david.umoru@edouniversity.edu.ng.

Contributions: The contribution of the study lies on its explanation of the increase of food commodity prices due to variability calculated in terms of depreciation in dollar exchange rate. Empirically, it is a confirmation of a significant structural problem, exchange rate variation as a cause of domestic inflation in selected African countries.

Limitations: Results have to be interpreted with care due to the small sample size. The results are rather a working hypothesis for future research.

Key words: Interest rate variation, exchange rate variation, commodity export, food commodity prices, Africa

JEL: A20, F46, G20

1. Introduction

Commodity exporting nations have significant terms of trade swings, making their actual exchange rate unstable. The volatility of the actual exchange rate harms the economy because it harms the consumption and investment decisions of private agents. Africa is not immune to such volatility in the actual exchange rate (Ricci, 2005). Although sustaining stable exchange rate regimes is challenging, it stimulates international trade and investment, in turn stimulation GDP growth. In 1973, the introduction of floating exchange rates in African countries added to the volatility of nominal and real interest rates, discouraging investment due to foreign exchange risk and increasing the transaction costs of international trade.

Floating exchange rates, in particular when leading to high volatility, can seriously hamper international trade. Besides exchange rate risk, unpredictability of exchange rates creates uncertainty about agreements with other countries. Volatility is defined as the danger or doubt related with unpredictable adjustment in exchange rates over time. Shocks in exchange rates are a major contributor to the unpredictability of commodity prices, inflation, lending rates, portfolio investments, savings and loans (Clarida, Gali 1994). Lending rates are used in financial market as benchmarks that reflect competition (Bostan, Firtescu 2019). This benchmark has increased in importance in the context of processes of globalization, the global financial recession, increasing rates of transmission and deregulation of capital movements and globalization.

A range of empirical studies show the effects of exchange rate variations on export and import, investment, as well as development of capital markets in emerging and developed markets (Schnabl 2008; Jamil et al. 2012; Alagidede, Ibrahim 2017; Dal Bianco, Loan 2017; Hatmanu et al. 2020). The link between exchange rates and interest rates is of great relevance, due to the importance of these variables in the composition of nominal and real economic changes, such as domestic inflation, the development of production, as well as exports and imports.

The relevance of the topic is increasing as some emerging market economies (EMEs) as some of them have recently implemented monetary and exchange rate policy reforms, trying to achieve their inflation aim under a flexible exchange rate regime. As many African countries heavily rely on the import and export of raw materials and food products, this study intends to establish the relation between exchange rate variations and changes food commodity price movements. In order to create proper economic policy in these resource-rich countries, it is necessary to better understand the link between commodity prices and exchange volatility. rates Addressing such concerns is important essentially from a political economy viewpoint. In fact, given the very high levels of commodity price volatility, in general, resource-rich countries must. Furthermore, commodity-exporting nations that open their capital accounts may have quite different experiences than other nations. In fact, the fluctuating and likely huge source of revenue from commodity exports can amplify the influence of capital account liberalization on the exchange rate.

2. Literature review

2.1. Conceptual issues

A currency exchange rate denotes the cost of one currency relative to another (Oloyede 2002). In the context of Nigeria, it refers to the number of naira required to securing one unit of another nation’s money, such as the dollar (Campbell 2010). According to Ahmed and Zarma (1997), the exchange rate is a key factor in decision-making in any country, making it a significant concern for any nation hoping to build its economy. Exchange rates, which are established by the interaction of supply and

demand in a free market system, are a reflection of how strong one currency is when compared to the currencies of other countries.

Currencies are immutable, and managed by using fixed and floating exchange rate schemes, or other mechanisms such as dual management (Onyeizugbe, Umeagugesi 2014). Exchange rate fluctuations will result in changing purchasing power and, as a result influence the level of imports and exports. On the other hand, adjustments to the level of industrial production will have a direct impact on imports as well as the exchange rate. Keynes (1960) argued that interest rates are a reward for temporarily resignation of the use of financial resources, not keeping them liquid. He puts emphasis on the loan interest rate in the interest rate concept. Adebiyi (2002) defines the interest rate as the return on capital or opportunity cost of postponing consumption. Returns on savings, loan rates, and discount rates are part of the interest rate. According to Professor Lerner's Jhingan (2003) definition, interest is the cost of the supply of "credit" or savings compared to net growth in quantity of money over time with respect to the demand for "credit" or investment. This definition means that the interest rate, like any other price, is a credit price determined by forces of supply and demand, in this case the supply and demand for loanable capital.

2.2. Theoretical literature

2.2.1. Optimal currency area (OCA) theory

The first and most influential theoretical framework for selecting an exchange rate regime was created by Mundel and McKinnon in 1961 and is known as the optimum currency area theory (1963). The stability of the business cycle and trade is the foundation of this idea. It emphasizes the ideas of shock symmetry, level of openness, and labour market mobility. This theory states that by lowering exchange rate uncertainty and thus the cost of hedging as well as interest rates, a stable exchange rate can either promote or decrease trade and economic growth. However, by stopping, postponing, or slowing the essential comparative price adjustment process, it can also lower trade and production growth (Erdemlioglu et al. 2012).

2.2.2. Monetary theory of exchange rate

According to the monetary theory of exchange rate, a nation's currency will appreciate as its money supply increases. The use of money has two significant effects. The first is the logical conclusion that a stronger currency is caused by increased relative income. The second is that a weaker currency results from a higher relative interest rate. According to the monetary model, there is a steady nominal demand for money over the long term that is favourably correlated with the amount of national income, but negatively correlated with interest rates. The country's money supply is equivalent to the fiscal base multiplied by the multiplier. The local credit created by the nation's monetary authority plus foreign exchange reserves forms the monetary base of the country. When there is an oversupply of money in the economy, it often leads to an outflow of reserves under a fixed exchange rate regime and a currency devaluation under a supple exchange rate regime. The opposite often occurs when there is excess demand for money (Olayungbo 2008).

2.2.3. Purchasing power parity theory

The relationship between price and exchange rate is described by the concept of purchasing power parity (PPP). The concept of PPP originated from the Salamanca School of Spain in the 16th century. Its recent application as a theorem of exchange rate determination dates back to the article of Gustav Cassel in 1918, who proposed PPP as a form of exchange rate determination – World War I exchange rate. Parity for nations that decide to yield to the gold standard after the conflict is over. A certain amount of adaptation was required since the rates of inflation in the nations that abandoned the gold standard in 1914 varied greatly both through and after the war. In our experience, the simplest and most robust PPP (Absolute PPP) format for determining exchange rates is based on international price law publications. Absolute PPP predicts that exchange rates should be modified to equalize the prices of baskets of national goods and services within two nations by market forces motivated by price differences (Cassel 1918).

2.2.4. Fisher's theory of interest rate

According to Fisher, fluctuations in the predicted rate of inflation are primarily responsible for variations in the short-term interest rate. Furthermore, Fisher's theory assumes that the market agents' assumptions regarding the rate of inflation are generally accurate. Fluctuations in inflation become a major factor in real interest rate changes. Since r is real interest rate, i is nominal interest rate, with p is the rate of inflation, we write $r = i - p$ (Mishkin, 2010). This well-known theory, which bears the name of American economist Irving Fisher (1930), serves as the foundation for the received view on interest rate formation. The theory states that competitive financial markets generate nominal interest rates on real assets because real assets often expand nominally in response to inflation and savers must persuade them to hold financial assets rather than real assets. The notable criticism of this concept is that it is insufficient since it considers only the assessment of the capital market and operates on the expectation that costs of goods and services are currently set (Mishkin 2010).

2.2.5. Loanable Funds theory of interest rate

According to the Loanable Funds theory of interest rate, the variables that influence the availability of loanable money determine the level of interest rates. According to Saunders (2010), this theory predicts interest rates based on the supply and demand for products. He continues by stating that, when all other circumstances are held equal, there is a greater demand for loanable funds when interest rates decline. Saunders recognized the following two elements as contributing to the shift in the demand curve for loanable funds: monetary expansions and economic circumstances. The loanable fund's hypothesis postulates that borrowing money today to take benefit of investment possibilities in the economy might increase future actual income. This will only be successful if the rate of yield on investment exceeds the cost of borrowing. These debtors would not agree to pay real interest rates that were higher than the rate of return on capital. Only if a genuine return on their investments is guaranteed, which will enable them to spend more in the future than they otherwise could, would savers be inclined to save and lend. People's taste for timing determines how much consumption they are prepared to delay (Saunders, Cornett 2011).

2.3. Review of empirical studies

Numerous studies have examined influence of interest rate and exchange rate volatility on commodity prices while considering the interrelationship between global commerce and capital flows. Using a GMM estimator, Umoru and Isedu (2018) studied the influence of exchange rate volatility on the total exports of African nations from March 1, 2005, to March 30, 2018, for the US dollar. The findings demonstrate that present and historical volatility had adverse and substantial effects on the combined exports of all the studied chosen African nations. For all nations, except Liberia, the speculative impact of currency rate fluctuation is detrimental and severe. Latief and Lefen (2018) investigated the association between exchange rate volatility, world trade and foreign direct investment (FDI) using GARCH (FDI) model. Statistical data were collected from 1995 to 2016 and the sample made of developing countries. The results of this study showed how important country-specific characteristics are. Exchange rate volatility had a significant favorable effect on trade, but had a significant negative impact in the case of Pakistan. The TGARCH measurement of exchange rate volatility had been shown to contain a remarkably favorable impact on international trade for nations such as Bhutan, Maldives and Nepal. The relationship between exchange rate volatility in addition to FDI had a significantly positive effect in India and Pakistan, but a significant negative effect in Bhutan and Nepal.

Bostan and Firtescu (2019) conducted research on the impact of the currency rate on Romania's competitiveness in international commerce. The study used OLS regression utilizing statistical data from the years 2007 to 2014. While Romanian exports and imports are endogenous factors, exogenous ones include exchange rate, inflation, and interest rate. They concluded that while the exchange rate is a key factor in determining competitiveness, uncertainty has differing effects on export and import. For imports, this effect seems likely less pronounced. The research by Frankel and Rose (2002), using data from over 200 nations to analyze the impact of currency union on trade and output, concluded that a monetary union is advantageous for all nations as part of the trade. They argued that the use of a single currency improved income per capita by at minimal a third of a percentage point for every one percent

increase in overall commerce. The second way to support the actual economy is to look at the relationship within investment and exchange rate instability. Additionally, there is disagreement among empirical research about how exchange rate volatility affects investment. According to research, currency rate volatility makes the economic environment unpredictable and discourages investing. The drop in investment has a detrimental effect on economic accomplishment.

Campa and Goldberg (1995) looked at the influence of exchange rate volatility in US industrial segments. They found that it had a negative influence on investment because high-margin businesses imbibe exchange rate variations by turning down actual investment. Udoka and Roland (2016) looked at how interest rate changes affect Nigeria's economic expansion. The link between interest rates and economic development, as well as the variation in economic development in Nigeria before and after the deregulation of the interest rates was explored.,. There was an interval association within interest rate and economic performance in Nigeria, according to the results. According to this, an increase in interest rates would lead to a decline in national GDP, slowing down he expansion of the real estate market. Using the Dixit-Pindyck model, Darby et al. (1999) found a considerable negative impact of increasing interest rate on investment.

Basing analysis on data from 10 nations in Latin America and the Caribbean, Dal Bianco and Loan (2017) examine how price and actual exchange rate volatility affects FDI influxes. The GARCH methods and data for the years 1990 to 2012 were used in this study. FDI was calculated as a percentage of GDP. The writers found that price unpredictability is irrelevant for the nations under study and that exchange rate volatility has a detrimental effect on FDI influxes in this area.

According to research by Bleaney and Greenaway (2001) conducted in 14 SSA nations between 1980 and 1995, exchange rate volatility has an impact on investment but not economic development. Aghion et al. (2009) expanded their research to 83 nations for the period 1960–2000. They discovered that the detrimental consequences of exchange rate fluctuation are displayed in nations where the financial market has not yet been established. This adverse effect is lessened in industrialized nations when riskier transactions are covered by hedging products Holland et al. (2011) found that a stable exchange rate has a positive impact on economic growth.

Jamil et al. (2012) studied effects of exchange rate volatility on development across two time interval for four non-Euro adopting nations and eleven European countries that are representatives of the European Monetary Union. For the nations analyzed, the findings are varied, although the common currency lessens the negative effects of exchange rate fluctuation on manufacturing productivity (Janus, Riera-Crichton 2015). Furthermore, both before as well as after the adoption of a single currency, exchange rate volatility had a detrimental effect on Germany and the Denmark.

For countries in the process of catching up with highly developed economies, where capital markets are still undeveloped and the possibility of macroeconomic instability is high, Schnabl's (2008) study shows a negative relationship linking economic development and exchange rate volatility. The study by Janus and Riera-Crichton (2015) uses the approximation of IV and found negative association between the real actual exchange rate volatility and economic development. However, Bagella et al. (2006) find that nations with flexible exchange rates enjoy further advantages than countries with fixed exchange rates, as they have less difficulties with absorbing surprises. Under this approach, nations with flexible exchange rate systems achieve economic success, and exchange rate instability helps them develop. The underlying hypothesis therefore is that exchange rate variability had no adverse effects on food prices in selected African countries.

3. Methodology

The study analyzes both static and dynamic relations between commodity prices, exchange rate and interest rate variation. For the static models, we conducted Hausman test to choose between random and fixed effects model while it also estimated differenced GMM and system GMM to ascertain dynamic relation, robustness, and also minimize endogeneity issues in our model specifications. Countries covered in this study included Ghana, Gabon, Tunisia, Nigeria, and South Africa and type of food exported by each country is detailed in Table 1. Country

selection was determined on basis of available data. The study covers the period, 1990M1 – 2021M12. Data were sourced from wits.worldbank.org/countries.

Table 1. Major food items exported by selected African countries

Countries	Major food exports
Ghana	Cocoa and timber
Gabon	Tobacco and oil kernels
Tunisia	Olive oil and fish products
Nigeria	Cocoa and sesame seeds
South Africa	Sugar and citrus fruits

Source: Authors' compilation.

3.1. Static specification

The study used a random and fixed effect model alongside the generalized technique of moments (GMM) to estimate the model. The GMM can help to resolve endogeneity, issues, particularly in the panel data studies (Sarafidis 2008). We begin with the panel fixed effect equation given as follows:

$$\ln y_{it} = \ln z_{it}\delta_i + v_i + e_{it} \qquad (1)$$

Using relevant variable notations, we have

$$\ln fdprc_{it} = \phi + \delta_{1i} \ln excrvar_{it} + \delta_{2i} \ln intrvar_{it} + \delta_{3i} \ln oilprc_{it} + v_i + e_{it}$$

where, $\ln fdprc_{it-1}$ lagged value of food prices, excrvar is exchange rate, intrvar is interest rate, oilprc is oil price variations, η_i is individual panel effect, and e_{it} is an idiosyncratic error term. Random effect OLS estimates in practice can be inefficient due to country-specific and time-specific effects.

$$\ln y_{it} = \alpha + \phi \ln z_{it}^{!} + \gamma \ln x_i^{!} + \eta_i + e_{it} \qquad (2)$$

Where a $z_{it}^{!}$ is vector of time varying regressors and $x_i^{!}$ is vector of time-invariant regressors.

3.2. Dynamic specification

3.2.1. GMM model

The differenced panel GMM was used to analyze the data after testing its suitability with the results from the GMM test and the fixed effects panel regression. The GMM model following specification:

$$\ln y_{it} = \delta \ln y_{it-1} + z_{it}^{!}\beta + (\eta_i + e_{it}) \quad (3)$$

The diff-GMM equation is then specified as

$$\Delta \ln y_{it} = \delta \Delta \ln y_{it-1} + \Delta z_{it}^{!}\beta + \Delta \upsilon_{it} \quad (4)$$

Using relevant notations for our variables, we have

$$\begin{aligned} \Delta \ln fdprc_{it} = {} & \delta \Delta \ln fdprc_{it-1} + \beta_{1i} \ln excrvar_{it} \\ & + \beta_{2i} \ln intrvar_{it} + \beta_{3i} \ln oilprc_{it} + (\eta_i + e_{it}) \end{aligned} \quad (5)$$

where all variables are as earlier defined.

3.2.2. GARCH model

To generate conditional variance of the exchange rate and interest rate variability among the selected ECOWAS countries, we specified our GARCH (1, 1). The GARCH model is robust in modelling volatilities (Musyoki et al. 2012):

$$e_t^2 = \delta + \sum_{j=1}^{p} \alpha_j e_{t-1}^2 \quad (6)$$

where u_t^2 is the conditional variance and u_{t-j}^2 is the previous period squared residual derived from previous period information about volatility. A reparameterization of ARCH (p) into GARCH model (1,1) equation yields:

$$\upsilon_t = \phi + \gamma \upsilon_{t-1} + \beta e_{t-1}^2 \quad (7)$$

where v_t is the conditional variance, β represents the ARCH parameters, γ denotes the GARCH parameter, e_{t-1}^2 depicts information about previous volatility measured as the lagged squared residual term and v_{t-1} is the previous forecast error variance.

4. Results and discussions

4.1. Descriptive analysis

In Table 2, the average (i.e. mean and median) of each series showed no good degree of consistency. This was demonstrated by the fact their values do not lie between the Maximum and Minimum values.

Table 2. Statistics

Statistics	fdprc	excrvar	intrvar	oilprc
Mean	4.6	700750	2.995.06	125.06
Media	0	130	0	120.79
Max	66.7	6.7	41.9	142.0
Min	0	0	-93.5	26.1
Std	11.7	2.2	10.4	15.6
Skweness	2.88	0.9	-3.1	7.4
Kurtosis	10.89	958	28.389	72.9
JB	3820	3664200	2764.65	20994.8
Obs.	960	960	960	960

Source: Authors' elaboration.

Nearly all of the chosen series had level spreads that were quite evenly distributed around their average. The low standard deviation values that each of the series had served as proof of this. The series, therefore, lacked very large values. Except for the interest rate, which was negatively skewed, all the factors were positively skewed. The coefficient of skewness indicates that all of the series was near to having a normal distribution since they were all symmetrical around the mean. All other series are not distributed properly in terms of Kurtosis. At the 5% level of significance, Jarque Bera and their associated probability displayed that all variables were not properly distributed.

4.2. ARCH test results

Arch test results of Table 3 confirm existence of volatility clustering. For both multivariate GARCH estimates with normal and t distributions, unconditional volatilities on diagonal elements are relatively high while correlations on off-diagonal elements are relatively low same. These are reported in Table 4.

Table 3. ARCH test results

LM statistic	CHSQ(1)= 96.6929	[.000]***
F-Statistic	F(1,3777)= 99.0450	[.000]***

Source: Authors' results.

**** indicates rejection of null hypothesis at 1% level*

Table 4. Unconditional volatilities/correlations

Variables	Volatilities
lnexcrvar _Ghana	.91466
lnexcrvar_Gabaon	.91242
lnexcrvar_Tunisia	.75833
lnexcrvar_Nigeria	.79117
lnexcrvar_S/Africa	.82130
lnintrvar_Ghana	-.51242
lnintrvar_Gabon	-.61604
lnintrvar_Tunisia	-.80409
lnintrvar_Nigeria	-.52686
lnintrvar_S/Africa	-.99917
Variables	Correlations
lnexcrvar _Ghana	.2166
lnexcrvar_Gabon	.20142
lnexcrvar_Tunisia	.34803
lnexcrvar_Nigeria	.10117
lnexcrvar_S/Africa	.21130
lnintrvar_Ghana	.21242
lnintrvar_Gabon	.41604
lnintrvar_Tunisia	.20409
lnintrvar_Nigeria	.22686
lnintrvar_S/Africa	.19917

Source: Authors' elaboration.

Table 5. GARCH with normal distribution

Variables	Estimate	t-ratio	Prob.
lnexcrvar _Ghana	.4200	71.1119	0.000
lnexcrvar_Gabon	.5920	182.7011	0.000
lnexcrvar_Tunisia	.6470	135.9445	0.000
lnexcrvar_Nigeria	.6420	281.962	0.000
lnexcrvar_S/Africa	.6020	410.545	0.000
lnintrvar_Ghana	-.0200	5.8790	0.000
lnintrvar_Gabon	-.0340	218.5502	0.000
lnintrvar_Tunisia	-.0260	7.9323	0.000
lnintrvar_Nigeria	-.1220	330.0937	0.000
lnintrvar_S/Africa	-.0276	29.8213	0.000
delta1	.1230	449.2606	0.000
delta2	.0210	15.2928	0.000
Maximized Log-likelihood = -9657.5			

Source: Authors' elaboration.

The result from multivariate GARCH with underlying multivariate normal distribution and the multivariate GARCH with underlying t distribution are presented in Table 5 and Table 6. Convergence was achieved after one iteration for normal distribution, whereas for t-distribution, convergence was achieved after 24 iterations respectively.

Table 6. GARCH with t-distribution

Variables	Estimate	t-ratio	Prob.
lnexcrvar_Ghana	.7110	122.7571	0.000
lnexcrvar_Gabon	.6110	232.2486	0.000
lnexcrvar_Tunisia	.7070	212.5872	0.000
lnexcrvar_Nigeria	.7124	195.7212	0.000
lnexcrvar_S/Africa	.6503	186.5949	0.000
lnintrvar_Ghana	-.2658	-6.0799	0.000
lnintrvar_Gabon	-.0917	-6.7613	0.000
lnintrvar_Tunisia	-.0505	-7.2501	0.000
lnintrvar_Nigeria	-.05412	-8.8712	0.000
lnintrvar_S/Africa	-.0987	-8.9579	0.000
delta1	-.0159	-512.3095	0.000
delta2	-.0191	-14.9974	0.000
df	26.8156		
Maximized Log-likelihood = -8920.1			

Source: Authors' elaboration.

Estimates demonstrate that volatility growth is highly significant for both normal and t distributions. However, when we compared normal and t-distributions, we found -9657.5 and -8920.1 for the normal and t-distribution respectively. Meanwhile, the value for the t-distribution is larger than that of the normal distribution. The df for our t-distribution is approximately 26.82 which is below 30, which further justifies basing empirical findings on t-distribution.

Results demonstrates that the Nigerian Naira had the highest coefficient of volatility of approximately 71.2%. The Nigeria naira showed negative and significant volatility. This was followed by the Ghanaian Cedi with a negatively volatility rate of 71% and thereafter, the South African rand with a coefficient of 65%. However, while all countries had negative volatility with respect to interest rate, only South Africa showed positive volatility in exchange rate of her currency. Ghana, Gabon, Tunisia,

and Nigeria faced negative exchange rate volatility. A possible explanation for this high volatilities in aforementioned countries is dominance of domestic inflation, which shows a significant structural problem.

Aligning with the preceding, is a resultant effect of instability of commodity prices which hinders implementation of economic policy. Changes in food prices most often reflect systemic shocks, which reduces supply of agricultural products and consequently escalate cost of supply. For consumers this leads to commodity price inflation. Prices of food commodities respond negatively to pervasive exchange rate shocks. Given the potential for increased transmission linking the volatility of food commodity prices and the currency exchange rate, countries that export commodities must assess the advantages and disadvantages of capital account liberalization. The contentious debate over whether capital regulation are necessary in light of the spikes in capital inflows that several developing markets are currently experiencing may also benefit from taking into account the unique challenges that commodity-exporting nations are currently facing and from putting more of an emphasis on exchange rate and short-term interest rate volatilities than their levels.

4.3. Static analysis

The static analysis as presented in Table 7 was carried out using the panel least square, fixed effect and random effect models. The most efficient model will be adopted for policy implications. The pooled least squares result revealed that a one-year lagged value of industrial output as well as oil price variations are significant in predicting current industrial output. Fixed effects panel OLS also had similar results with a one-year lagged value of industrial output and oil price variation individually significant in the model. Exchange rate devaluation has a negative relationship with industrial output in both estimations, but this effect is insignificant at the 5 percent level of significance. However, these estimations are criticized for being downward biased.

Table 7. Panel OLS estimates

Variables	Pooled least squares
lnfdprc(-1)	0.490*** (124.589)
lnexcrvar	1.134** (2.586)
lnintrvar	0.129*** (90.278)
lnoilprc	-0.149*** (-5.108)
c	1.120*** (100.249)
Adjusted r-squared	0.462
Variables	Fixed effects least squares
lnfdprc(-1)	0.563** (2.472)
lnexcrvar	0.122*** (19.421)
lnintrvar	0.109*** (300.578)
lnoilprc	-1.084** (-2.468)
Adjusted r-squared	0.562

Source: Authors' elaboration.

The pooled least squares result revealed that exchange rate and interest rate variations are significant in predicting current commodity prices. However, the effect of these variations is significantly negative and the impact of exchange rate variability is enormous compared to that of interest rate variation.

The Hausman test is commonly adopted in literature when deciding which model, fixed or random, is more efficient and consistent (preferable). The test checks the null of efficient and consistent REM against the alternative hypothesis. From result presented in Table 8, FEM is found relevant. Fixed effects panel OLS also had similar results for both exchange rate and interest variations. These estimations are criticized for being static in nature.

Table 8. Hausman test

Model	Chi-sq	p-value
FEM(1), REM(1)	11.121776	0.0252
FEM: Fixed effect model, REM: Random Effect model* p<0.05 ** p<0.01 *** p<0.001.		

Source: Authors' elaboration.

First differenced panel GMM was estimated with same dataset and results are as reported in Table 9. To determine the presence of bias in GMM output, the coefficient of the one-year lagged value of the dependent variable was compared with the coefficient of same in fixed effects regression output. The fixed effects coefficient is 0.563 and is higher than its differenced panel GMM counterpart, of 0.374. Therefore, the diff-GMM estimator in this paper suffers from downward bias despite Arellano-Bond serial correlation test shows absence of second-order serial correlation (p=0.79>.05). The foregoing necessitated system GMM as suitable for determining the impact of exchange rate and interest rate variations on commodity prices in Africa.

Table 9. Differenced GMM results

Variables	Differenced panel GMM	t-values
c	10.2897** (0.001)	4.2795
lncomp(-1)	0. 374*** (0.000)	102.476
lnexcrvar	0.115*** (0.000)	90.684
lnintrvar	0.004*** (0.000)	116.785
lnoilprc	-1.091*** (0.000)	-145.586
Effects Specification: Cross-section fixed (first differences)		
AR(1)	-2.9917(0.0000)***	
AR(2)	-0.261954 (0.7934)	
***(**) significant @ 1% (5%)		

Source: Authors' elaboration.

4.4. Dynamic analysis

To understand the dynamic relationship, the system GMM, whose estimation requires setting instruments, was estimated accordingly. The sys-GMM uses the differences of the lag variables as instruments for the level equation and lags of the variables at levels as instruments for the difference equation. The GMM can correct for endogeneity and autocorrelation which is common in panel studies and this makes it statistically more robust for our analysis. The results sys-GMM are presented as dynamic in Table 10 below. Food commodity prices in the immediate past period are responsible for 0.31% of price level change in the present period in the same direction. Exchange rate variation was found to adversely influence food commodity prices in African nations by 1.091%. The relationship is positive, revealing that food commodity price rises as exchange rate fluctuate. Variation in interest rate was also found to be a significant predictor of commodity prices with a negative impact. Worsening exchange rates of local currencies against the dollar and unstable movement in short-term interest rate inflate commodity prices in Africa. Precisely, a 1% rise in variation in short-term interest rate heads to a proportionate increase in food prices by 1.01% respectively. Our findings also suggest that these factors are important drivers of food commodity prices in Africa.

This finding agrees with those reported in studies of Umoru and Isedu (2018), Brahmasrene et al. (2014), Sensoy et al. (2014) and Anjum (2019). The system-GMM estimates show positive and significant effect of previous prices on current food price level. The significance of lagged coefficient validates dynamic relation between commodity prices, exchange rate and short-term interest rate variation. Oil prices variability had a negative relation with commodity prices. Increases in oil prices is a major factor behind a strong increase in food prices in Africa. This could be explained by the fact that oil is an important input in industries and agriculture (production of final goods and services). Hence, increase in cost of oil, increases production cost which translates into increasing commodity prices consequently. The significance of oil prices could be a consequence of the increase in fluctuation of exchange rates in relation to the dollar. The probability value of J-static is significant implying none over-identifying restrictions in the model.

Table 10. System-GMM results

Variable	Sys-GMM coefficient	t-statistic
c	10.456*** (0.000)	211.9056
lnfdprc(-1)	0.3163*** (0.000)	1560.578
lnexcrvar	1.091*** (0.000)	124.578
lnintrvar	1.014 (0.000)***	23357.47
lnoilprc	-0.03594*** (0.000)	-18607.88
Hansen J-statistic	784.2755	
Prob(j-statistic)	0.000000	
***Significant @ 1%		

Source: Authors' elaboration.

5. Conclusion

In this study, we examined how variations in exchange rates of selected African nations against the US dollar affect food commodities prices. Our first findings show that volatility growth is highly significant in all countries examined. The Nigerian Naira had highest coefficient of volatility of approximately 71.2%. The Nigeria naira showed negative and significant volatility. This was followed by the Ghanaian Cedi with a negative volatility rate of 71% and the South African rand with a coefficient of 65%. However, while all countries had negative volatility with respect to the interest rate, all countries, except Ghana, showed positive volatility in the exchange rate of their currency. Ghana, Gabon, Tunisia, and Nigeria showed negative exchange rate volatility. The high volatilities can be a determinant of high inflation rates in these countries.

The outcome, therefore, adds to a lengthy list of difficulties faced by nations that export primary products. Given that food commodity prices have moved into an era of rising instability, the spread of instability out of the oil prices to the exchange rate is a difficulty that is undoubtedly going to stay at the top of policymakers' agendas. Indeed, a flight to commodities has resulted from the perceived scarcity of secure possessions at the start of the financial crunch, which has caused a dramatic rise in the

prices of these commodities. Exporters of food commodities should weigh the advantages and costs of capital account liberalization against fluctuations in commodity prices and greater transitivity between main variables such as exchange rates with lending rates (interest rates). The fierce debate over whether capital controls can match the surge in capital influxes faced by some developing markets can additionally be beneficial when taking into account the specific circumstances faced by countries. Governments and policymakers must implement policies that increase demand for the African currency in order for it to appreciate against the US dollar. This would allow the price of oil to decrease in the face of exchange rate fluctuation in relation to US dollar. When exchange rates play an important role in primary commodity prices, it is necessary to minimize volatility in exchange rates. Furthermore, excessively high short-term interest rates should be prevented in order to mitigate the negative influence on food commodity prices.

References

Aghion P., Bacchetta P., Rancière R., Rogoff K. (2009), Exchange rate volatility and productivity growth: the role of financial development, "Journal of Monetary Economics", vol. 56 no. 4, pp. 494–513.

Aizenman J. (1992), Trade reforms, credibility, and development, "Journal of Development Economics", vol. 39 no. 1, pp. 163–87.

Alagidede P., Ibrahim M. (2017), On the causes and effects of exchange rate volatility on economic growth: evidence from Ghana, "Journal of African Business", vol. 18 no. 2, pp. 169–193.

Bagella M., Becchetti L., Hasan I. (2006), Real effective exchange rate volatility and growth: a framework to measure advantages of flexibility vs. costs of volatility, "Journal of Banking Finance", vol. 30 no. 4, pp. 1149–1169.

Bostan I., Firtescu B. (2019), Exchange rate effects on international commercial trade competitiveness, "Journal of Risk and Financial Management", vol. 11 no. 2, art. 19.

Clarida R., Gali J. (1994), Sources of real exchange-rate fluctuations: how important are nominal shocks?, "Carnegie-Rochester Conference Series on Public Policy", vol. 41, pp. 1–56.

Dal Bianco S., Loan N.C. (2017), FDI inflows, price and exchange rate volatility: new empirical evidence from Latin America, "International Journal of Financial Studies", vol. 5 no. 1, art. 6.

Dwivedi D.N. (2014), Managerial economics, 6th ed., Vikas Publishing House PVT, New Delhi.

Erdemlioglu D., Laurent S., Neely C. (2012), Econometric modeling of exchange rate volatility and jumps, Federal Reserve Bank of St. Louis Working Paper Series, Working Paper 2012-008A.

Fedderke J. (2010), Sustainable growth in South Africa, in: Growth and sustainability in Brazil, China, India, Indonesia and South Africa, OECD Publishing, https://www.oecd.org/brazil/growthandsustainabilityinbrazilchinaindiaindonesiaandsouthafrica.htm [20.09.2022].

Frankel J., Rose A. (2002), An estimate of the effect of common currencies on trade and income, "The Quarterly Journal of Economics", vol. 117 no. 2, pp. 437–66.

Hatmanu M., Cautisanu C., Ifrim M. (2020), The impact of interest rate, exchange rate and European business climate on economic growth in Romania: an ARDL approach with structural breaks, "Sustainability", vol. 12 no. 7, art. 2798.

Holland M., Flavio V., Cleomar G., Luiz C.B. (2011), Growth and exchange rate volatility: a panel data analysis, "Applied Economics", vol. 45 no. 26, pp. 3733–41.

Jamil M., Erich W.S, Robert M.K. (2012), Exchange rate volatility and its impact on industrial production, before and after the introduction of common currency in Europe, "International Journal of Economics and Financial Issues", vol. 2 no. 2, pp. 85–109.

Janus T., Riera-Crichton D. (2015), Real exchange rate volatility, economic growth and the euro, "Journal of Economic Integration", vol. 30 no. 1, pp. 148–171.

Keynes J.M. (1960), The general theory of employment, interest and money, Macmillan & Co, New York – London.

Latief R., Lefen L. (2018), The effect of exchange rate volatility on international trade and foreign direct investment (FDI) in developing countries along "one belt and one road", "International Journal of Financial Studies", vol. 6 no. 4.

Mistikin S.F. (2010), The economies of money, banking and financial markets, 9th ed., Addison Wesley, Boston.

Niyimbanira F. (2013), An investigation of the relationship between oil prices and inflation in South Africa, "Mediterranean Journal of Social Sciences", vol. 4 no. 6, pp. 105–112.

Olayungbo D.O., Yinusa D.O. Akinlo A.E. (2008), Exchange rate volatility in primary and manufacturing sectors: manufacturing sectors in Sub Sahara, LAP Lambert, Chisinau.

Onyeizugbe C.U., Umeagugesi U.E. (2014), Exchange rate management and the survival of the industrial subsector of Nigeria, "Global Journal of Management and Business Research", vol. 14 no. 10, pp. 13–18.

Ricci L.A. (2005), South Africa's real exchange rate performance, in: Post-apartheid South Africa: the first ten years, Nowak M., Ricci L.A. (eds.), International Monetary Fund, Washington, DC.

Saunders A., Cornett M., Erhemjamts O. (2011), Financial institution management. A risk management approach, 7th ed., McGraw Hill, New York.

Schnabl G. (2008), Exchange rate volatility and growth in small open economies at the EMU periphery, "Economic Systems", vol. 32 no. 1, pp. 70–91.

Udoka C.O., Roland A. (2016), The effect of interest rate fluctuation on the economic growth of Nigeria, "International Journal of Business and Social Science", vol. 3 no. 20, pp. 295–302.

Umoru D., Isedu M. (2018), Africa's trade and volatility in exchange rate: an econometric calculation, "Journal of Academic Research in Economics", vol. 10 no. 2, pp. 218–238.

CENTRAL EUROPEAN REVIEW
OF ECONOMICS AND MANAGEMENT

ISSN 2543-9472; eISSN 2544-0365

Vol. 6, No.3, September 2022, 69-86

www.cerem-review.eu
www.ojs.wsb.wroclaw.pl

The impact of teaching interventions in education for sustainable development – an experimental case study

Johannes (Joost) PLATJE, Aniela STYŚ
WSB University in Wrocław, Poland
Markus WILL
University of Applied Sciences Zittau/Görlitz, Germany
Wim LAMBRECHTS
Open University of the Netherlands

Received: 11.08.2022, Revised: 23.09.2022, Accepted: 23.09.2022
doi: https://dx.doi.org/10.29015/cerem.957

Aim: Questionnaire research can be used as a teaching instrument and to measure the impacts of education for sustainable development. This paper presents a case study of a teaching intervention regarding students' perception of operations and (supply) management fragilities, such as dependency on few customers or suppliers; difficult to find employees; and low probability, high impact events for business sustainability. The teaching intervention focused on side effects of innovations, leading to vulnerabilities that can threaten the existence of an enterprise. This research was carried out in the context of the capacity for creating an Early Warning System for small probability, high impact events. The following issues are addressed in the paper: 1). The impact of the teaching intervention on students' perceptions; 2). Differences in perception between non-attending (N = 128) and attending students (pre-test N = 139; post-test N = 119).

Design / Research methods: This paper discusses whether teaching interventions can influence the awareness of fragility issues as well as low probability, high impact events. The case-study is based on an experiment in a marketing course for management students of a large private business school in Wrocław (Poland) in April–May 2019. Before start of classes students filled out a questionnaire (Attending Students). A teaching intervention slide was used in every lecture. At the end of the course, all students (also the students absent during the first classes) filled out the repeat questionnaire. Statistical analysis was carried out whether there were differences between Attending Students filling out both questionnaires, and students only filling out the repeat questionnaire (Non Attending Students).

Correspondence address: Markus WILL, University of Applied Sciences Zittau/Görlitz, Germany. E-mail: m.will@hszg.de.

Conclusions / findings: The findings show that students struggle to grasp the complexities and uncertainties surrounding sustainability and fragility issues in relation to the business context. The teaching interventions had limited impact on the ability of students to engage in these issues, albeit significant differences between attending and non-attending students were observed. A limitation of the results is that this study only concerned a case study of a specific group of students. An implication requiring deeper research is that while teachers can do in-depth exercises and provide lectures, a part of the students, being less motivated to obtain knowledge, is unlikely to grasp sustainability issues, when not included in assignments, examination preparation, or compulsory rather than elective courses.

Keywords: education for sustainable development, fragilities, Black Swans, innovation for sustainable development

JEL: I21, O31, Q01

1. Introduction – the importance of teaching interventions in education for sustainable development

In recent decades, Higher Education Institutions worldwide have been called to contribute to education for sustainable development (Lozano et al. 2013), as well as fostering knowledge which can support innovations for sustainable development (Wright 2007; Novo-Corti et al. 2018). However, education as well as innovations for sustainable development may not always be in line with the students' aims and motivations, as well as short term, profit-oriented goals in business. Increasingly, higher education is criticized for its focus on economic objectives, influenced by neoliberalism (Bessant et al. 2015; Nussbaum 2010). As a result, students focus on obtaining a diploma to enter or stay in the labour market (Molho 1997), rather than a broad learning process which enables them to lead meaningful lives (Lambrechts et al. 2018a; Nussbaum 2010). This also contradicts the Sustainable Development Goals (SDGs), as these long-term goals may conflict with short-term, myopic goals of students and companies (Alvesson, Spicer 2012). In the line of Lambrechts et al. (2018a), education for sustainable development aims at "preparing students for wicked problems (Rittel, Webber 1973; Levin et al. 2012) featured by complexity and uncertainty (Lambrechts, Van Petegem 2016), and preparing students to deal with limits to knowledge as well as with the existence of unseen evidence, threatening sustainability in a complex and uncertain world (Kahneman 2011; Taleb 2012)." (quote from Platje et al. 2019).

However, while sustainability is becoming increasingly important in business, traditional business studies focus on neo-liberal paradigms, where ecosystems are considered to be resilient, and growth, technology and innovations are supposed to solve different types of challenges to sustainable development in general, and sustainable business in particular (Gladwin et al. 1995; Carson 2002). This has been outlined by Elkington (2018), who criticized limited approaches of his Triple Bottom Line (TBL), in which the economic dimension overshadow the social and environmental dimensions. Instead, more holistic and systemic interpretations are called upon, that critically question the growth-oriented economic systems (Mitchell et al. 2020). It is hardly considered that markets and the business environment are more random and volatile than is often presented in mainstream business approaches (Mandelbrot, Hudson 2008), while the solution to a certain problem of challenge (e.g., an innovation), through dynamic effects are likely to cause new challenges to the sustainability of business (Sterman 2000; Taleb 2012). In particular when fragilities appear, as focused upon in the teaching experiment presented in this paper, the company becomes more vulnerable to random events, in turn increasing the importance of managing small probability, irreversible high impact events (Taleb 2012; Taleb et al. 2014). Awareness of this issue is a pre-condition for dealing with potential threats, and eventually applying the precautionary principle (Rao 2000).

The focus in this paper is on whether teaching can influence the awareness of fragility issues as well as low probability, high impact events, by means of an experiment in a marketing course for management students of a large private business school in Wrocław (Poland) in April–May 2019. Business students have been described in the literature as being strongly focused on economic gain and bottom line thinking, yet recent studies added nuance to the debate, describing different segments when it comes to perceptions regarding sustainability (Lambrechts et al. 2018b) and pro-environmental behavior (Caniëls et al. 2021).

The following issues are addressed in the paper: 1). The impact of the teaching intervention on students' perceptions; 2). Differences in perception between non-attending (N = 128) and attending students (pre-test N = 139; post-test N = 119); 3). The acceptance of increased fragilities in the company due to innovations, and the implication for innovation for sustainable development.

2. Theoretical framework

The sustainability of many systems, including industries and business, is challenged by increased interconnectiveness in the global economy (Taleb 2012). Also, social and ecological systems are more interconnected due to increased trade flows, increased travel opportunities, etc. (Harari 2015). This process adds to the complexity of global supply chains, and increases the importance of unexpected events appearing (Casti 2013; Taleb 2012), which may threaten business sustainability in case of existing vulnerabilities or fragilities. While research on these issues has been presented in the last decade, the COVID-19 pandemic was a clear example and reminder of how fragile global economic systems are, pointing towards the importance of resilient supply chains (Linton, Vakil 2020). As a consequence, the identification of such fragilities or vulnerabilities becomes more and more important. Thus, it becomes important to prevent or reduce ignorance of potential low probability threats that can threaten the viability and sustainability of enterprise (Amoyette et al. 2014). This can be expressed by the level of functional stupidity (Alvesson, Spicer 2012), which, together with awareness of fragilities, worldviews (paradigms, mental models) and trust is a determinant of the capacity to create a so-called Early Warning System (EWS), a kind of "smoke detector" that catches weak signals indicating a potential disaster (Bertoncel et al. 2018). "Early warning systems serve as a key management tool for anticipating potential disasters or other negative events" (Trzeciak, Rivers 2003, cited in Bertoncel et al. 2018: 407).

In order to be able to design, create, implement and use an EWS for unexpected events that may cause irreversible damage, four determinants have been identified (see Platje et al. 2019): Awareness of vulnerability and fragility (Mandelbrot, Hudson 2008; Taleb 2008), functional stupidity (Alvesson, Spicer 2012), general trust (Raiser 1997, 1999) and worldviews (Meadows 1999) expressed by adherence to technocentric paradigm (Gladwin et al. 1995). These determinants are presented in Table 1, together with the effects as well as the questions asked in the questionnaire. The teaching intervention concerned a) awareness of fragility issues, and b) low probability and high impact events as an element of (lack of) functional stupidity, as

this fits in the existing curriculum of the course. Worldviews are not dealt with in this paper.

Table 1. Determinants of the capacity to create an Early Warning System (EWS)

Determinants of EWS and possible effects	Questions asked in questionnaire
a. Awareness of fragility issues, a vulnerability that may lead to a serious crisis or (irreversible) collapse scenarios. Awareness of a problem is a part of the solution (Taleb 2012), and supports the development of an EWS for unexpected high impact, irreversible events (Black Swans – Taleb 2007).	A1. It is no problem for a company when it is dependent on one or a few main suppliers. A2. It is no problem for a company when it is dependent on one or a few customers. A3. It is no problem when the innovations of a company make the management more complex. A4. It is no problem when innovations of a company increase the reliance on high skilled, difficult to find employees. A5. It is no problem when the innovations of a company make it reliant on one or two suppliers. A6. It is no problem when the innovations of a company make it reliant on one or a few customers. A7. It is no problem when a company depends on high skilled, difficult to find employees.
b. Functional stupidity. If the lack of capacity or willingness to use and apply knowledge (Alvesson, Spicer 2012) and to deal with uncertainty as well as small probability, high impact events in decision making. Functional stupidity means „an absence of reflexivity, a refusal to use intellectual capacities in other than myopic ways, and avoidance of justifications" (Alvesson, Spicer 2012: 1188). Mistakes are not a source of knowledge, and may accumulate into different kinds of vulnerabilities / fragilities unnoticed by the management, The higher the level of Functional Stupidity, to lower the capacity to create an EWS.	B1. It is no problem when a company ignores threats to its existence which are difficult to quantify. B2. It is no problem when a company ignores low probability threats B3. A company should take unlikely disasters into consideration in crisis management. B4. Companies can neglect low probability threats in their risk management.

Table 1. Cont.

c. General trust and process based trust. General trust exists when we trust unknown people or institutions. Process-based trust relates to trust appearing through repeated contact with people we know directly (Raiser 1997, 1999). A high level of general trust increases the ability to react to unexpected events, as well as the absorption of information and knowledge. Process-based trust can lead to the development of groups and networks closed to new ideas from outside (Raiser 1997, 1999), increasing the transaction costs of finding solutions in case of a crisis.	General trust: C1. In general, people can be trusted. Process-based trust: C2. In general, lecturers at our university can be trusted. C3. In general, students at our university can be trusted. C4. In general, my class mates can be trusted. C5. In general, businessmen can be trusted.
d. Adherence to the technocentric paradigm. Technology and economic growth are supposed to enable solutions for all types of challenges and crises (Gladwin et al. 1995). As low probability, high impact events are considered to be irrelevant or non-existent, they are likely to be ignored and an EWS may be considered unnecessary.	D1. Technology will solve eventual problems with energy supply in the future. D2. Innovations and development of technology will solve problems with environmental pollution and overuse of natural resources.

Source: adapted from Platje (2019); Platje, Zepeda (2019); Platje et al. (2019), based on Alvesson, Spicer (2012); Gladwin et al. (1995); Taleb (2012); Mandelbrot, Hudson (2008).

3. Methodology and hypothesis regarding the teaching intervention

One element of this research is the issue of non-attending students. In theory, students should be eager to obtain knowledge, and be motivated to obtain skills and abilities for dealing with issues of sustainable development. However, there may be different problems with this. While the student may, for example, be motivated to obtain skills and knowledge, the priority may be income and opportunities in the labour market (e.g. Becker 2009). While not all teachers and scientists are interested in developing knowledge, but just doing a job which gives them income (e.g. Smith [1776] 1998), also students may have weak motivation in obtaining knowledge, and rather focus on passing exams in order to obtain a diploma (e.g. Molho 1997). In the experiment this is addressed by researching students attending and students not attending classes, but taking part in the final examination. For the aim of the research, the following hypotheses have been formulated:

Hypotheses 1. There is no impact of the teaching intervention on the students' perception.

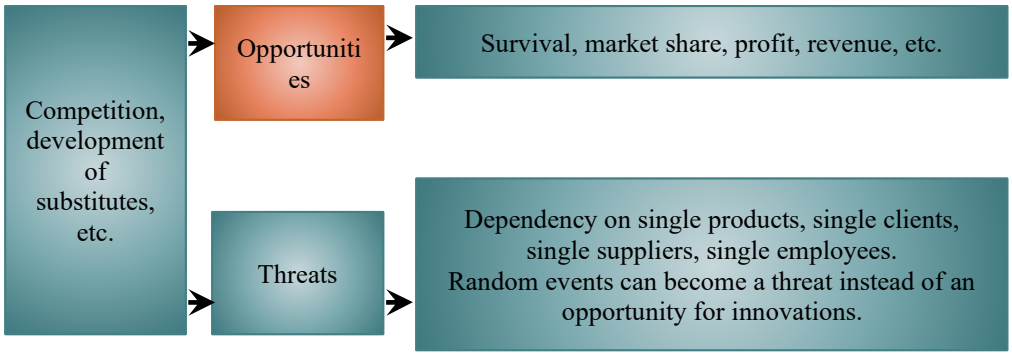
Hypothesis 2. Attending Students perceive fragilities and low probability, high impact events as more problematic than Non Attending Students (NAS).

The research was carried out in 2018 during a marketing course for first year management students at a large private university in Poland. The research was conducted as follows. At the beginning of the course, all attending students filled out the questionnaire. The questionnaire contained 44 statements, of which 19 were relevant for the teaching experiment. Each student received an individual anonymous code, which should be used when filling out the repeat questionnaire at the end of the course. Some credit points could be earned for delivering the repeat questionnaire, also for those who did not fill out the questionnaire at the beginning of the course (the absentee group). As all students attending during the last meeting obtained some credits, and the questionnaire was collected in bulk, anonymity was assured.

Two groups were considered for analysis: Attending students (AS) and non-attending students (NAS). The students who filled out the initial questionnaire and the repeat questionnaire were assumed to be the attending students, while those who only filled out the repeat questionnaire were assumed to be rather non-attending students. The explanation for this is that there were only 3 lectures, each 90 minutes, as a general introduction to more in-depth exercise groups. In each lecture, a teaching intervention was conducted by one of the co-authors, using the slide presented in Figure 1. Focus was on innovations and innovation management, and the potential advantages and threats of such innovations for sustainable development. This issue fit in the curriculum of the course.

The main line of thought in this study is whether students can image that innovations and solutions for existing problems may lead to new problems, potentially threatening business sustainability and survival? In other words, do they consider the appearance of fragilities, making a company more vulnerable to random events, causing potential non-linear, irreversible damage? (Platje et al. 2019; Taleb 2012).

Figure 1. Slide used for teaching intervention – topic Innovation Management



Source: prepared by Johannes Platje and Markus Will.

The reason the topic of innovation management was focused upon, is that it is not only an important element of the large majority of business studies, but also supposed to be important in achieving sustainable development as Goal 9 of the Sustainable Development Goals (SDG) is: "Build resilient infrastructure, promote sustainable industrialization and foster innovation."[1] It is stated that: "Technological progress is the foundation of efforts to achieve environmental objectives, such as increased resource and energy-efficiency. Without technology and innovation, industrialization will not happen, and without industrialization, development will not happen."[2] It seems that innovation and technological progress is considered to be a precondition for sustainable development, as they allow for industrialization, which is a precondition for achieving economic growth (Schumpeter 1942; Jacobs 1986), and in turn social and economic goals of sustainable development. This seems to be in accordance with the techno-centric paradigm (Gladwin et al. 1995), where growth and technological progress are assumed to solve all kinds of environmental problems.

While innovation is important for the viability of business (the opportunities shown in Figure 1 focus on this issue), the presented threats go beyond standard risk of failure. Even when innovations seem to be successful, different, often unexpected,

[1] https://www.un.org/sustainabledevelopment/infrastructure-industrialization/ Goal 9: Build resilient infrastructure, UN Sustainable Development Goals: Goal 9 – promote sustainable industrialization and foster innovation [14.09.2019].
[2] Ibid.

side effects may appear (Jevons 1906; Sterman 2000; Taleb 2012). First of all, different fragilities may appear, like increasing reliance on a few suppliers, customers or employees. At this moment, random events in the external environment may lead to a threat for the company (Taleb 2012). Innovation seems to be a kind of "mantra", a solution to all types of problems. This was expressed in the questionnaire research by questions whether innovation and technology can solve problems with energy supply in the future, and can solve appearing environmental problems as well as overuse of natural resources. This raises the question, in case of existing fragilities in a system (e.g., dependency on a specific energy source), what would happen when new technology appears too late. This line of thinking concerns scenario thinking, according to the question "What's the worst that could happen" (Craven 2010). Besides fragilities, another issue is whether a technological fix for a certain problem creates another problem, whether this problem is manageable, or can create a threat to the existence of a system or an organization.

4. Results and discussion

Having a picture of the student's profile can be useful for preparing classes, in order to find a focus for in class discussion. When knowing the perceptions of the students, information is available about which issues may be controversial, and which issues may need special attention. The students in our sample were first year students of management of a large private business university in Poland, who have a (often full time) job and study during the weekend. Compared to a group of logistics students, where a teaching intervention on sustainable transport systems was carried out in 2018 (Platje et al. 2019), the students show a different profile. Analysis of questions on elements of functional stupidity (not further discussed in this paper, but relevant for future teaching interventions) shows that reflexivity (the possibility to doubt and criticize management decisions in a company; openly discussing changes in the rules in a company) and justification (management explaining their decisions; providing feedback) (Alvesson, Spicer 2012) are perceived to be more important for management students than for logistics students. While in both groups the lack of

reflexivity and justification is seen as problematic, the issue may require more attention for the logistics students when dealing with management of innovations for sustainable development.

Analysis of the Attending Students (AS) and Non-Attending Students (NAS) of the experiment discussed in this paper, indicates that the groups differ. However, this difference in only significant regarding the need to provide feedback. On a Likert-item scale from 1-5, where the statement was assessed whether something is not a problem (1 – totally disagree, 5 – totally agree), the mean for NAS was 1.82, and for NA 1.39 in the pre-test and 1.51 in the post-test, both showing a significant difference with the mean for NAS.

The level of trust was measured in the pre- and post-test. No significant difference was observed neither between the pre- and post-test for AS, nor between AS and NAS (Table 2). General trust is low, as can be expected as Poland is rather a low-trust society (see, e.g. Kochanowicz 2004). On a scale from completely disagree (1) to 5 (completely agree) to the statement "In general, people can be trusted", the mean for the three groups ranges from 2.51 to 2.69 (Table 2). No significant difference was observed. General trust is correlated for all three groups with other types of rather process-based trust in lecturers (correlation coefficient (Kendall's Tau) ranging from 0.226 to 0.436), students at the university (correlation coefficient ranging from 0.290 to 0.399) and class mates (correlation coefficient ranging from 0.274 to 0.340) at a significance level ($p < 0.001$). Trust in lecturers (mean ranging from 3.65 to 3.75) and class mates (mean ranging from 3.62 to 3.66) is medium high, while students at the university are a bit trusted. Trust in Businessmen is rather low (mean ranging from 2.35 to 2.67). Regarding AS-pre and AS-post as well as NAS, no significant differences were observed between the means at $p<0.001$

A possible implication is that the relatively high trust in lecturers and classmates is a factor supporting the educational process. The low general trust and trust in businessmen can be a factor hampering the process of innovation for sustainable development, as this may hamper cooperation and information flows. These issues can be a good topic for discussion in class on managing innovations for sustainability.

Table 2. Trust – means and standard deviations

	AS pre	Standard Deviation	AS post	Standard Deviation	NAS	Standard Deviation
C1. In general, people can be trusted.	2.51	1.11	2.69	1.09	2.62	1.05
C2. In general, lecturers at our university can be trusted.	3.75	0.764	3.73	0.685	3.65	0.947
C3. In general, students at our university can be trusted.	3.24	0.879	3.32	0.834	3.36	0.990
C4. In general, my class mates can be trusted.	3.66	0.856	3.63	0.809	3.62	0.980
C5. In general, businessmen can be trusted.	2.35	0.847	2.49	0.859	2.67	0.952

Source: authors' own research.
AS pre = Attending Students pre-test; AS post = Attending Students post test; NAS = Non Attending Students

As innovations tend to produce side effects, the following statement was formulated "The world increases in complexity so fast, that increase in knowledge cannot keep up." The means ranged from 3.02 for NAS to 3.16 for AS-pre and 3.36 for AS-post, i.e., neither agree, nor disagree. While there is no significant change between the pre- and post-repeat groups, after finishing the course, the repeat group shows a significant higher agreement with the increasing complexity-knowledge gap than the non-repeat group. This brings forward a hypothesis to be tested in future research: class attendance leads to recognition of an increasing complexity-knowledge gap. However, no significant correlation with other statements were observed.

An issue is whether increasing complexity due to innovation is considered to be problematic (question A3). While the mean respondent tends to see this as neither problematic, nor unproblematic, increasing complexity is considered to be more problematic by the post-repeat group after the teaching intervention. In order to assess whether innovation leads to higher acceptation of increasing fragilities questions were

asked whether dependency of a few suppliers, customers and high skilled, difficult to find employees is problematic. Additionally, it was asked whether increase in such dependency is problematic. The results are presented in Table 3. The teaching intervention does not show a significant impact at a level of significance of $p<0.01$. However, except for dependency on suppliers (A1 and A5), the AS group perceives increasing management complexity and dependency on a few customers or employees as more problematical than NAS.

Another issue researched was the awareness of so-called Black Swans, i.e., low probability, high impact events (Taleb 2007). A distinction was made between difficult to quantify threats (B1) and low probability threats (B2, B3 and B4). While questions B1 and B2 focus on ignorance of threats, questions B3 and B4 concern the inclusion of threats into risk and crisis management. The following results were obtained:

- Both AS and NAS consider ignorance of Black Swans as problematic. No significant difference was observed at $p<0.01$.
- Both AS and NAS think Black Swans should be included in crisis and risk management.
- The teaching intervention only had a significant impact on question B2 (a significant difference between AS pre and AS post at $p=0.002$; a significant difference between AS post and NAS at $p=0.022$).
- The notion “crisis management” in question B3 seems to increase the willingness to include low probability threats in crisis management, compared to risk management mentioned in question B4. This may imply that framing Black Swans properly may be of importance in order to have it considered in company management.

Table 3. Fragilities – means and standard deviation

	AS pre	Standard Deviation	AS post	Standard Deviation	NAS	Standard Deviation
A1. It is no problem for a company when it is dependent on one or a few main suppliers.	2.28	1.04	2.03	0.872	2.50	1.09
A2. It is no problem for a company when it is dependent on one or a few customers.	2.05	0.942	1.95	0.889	2.50	1.17
A3. It is no problem when the innovations of a company make the management more complex.	2.84	1.15	2.46	1.08	2.86	1.18
A4. It is no problem when innovations of a company increase the reliance on high skilled, difficult to find employees.	2.77	1.07	2.55	0.883	2.71	0.951
A5. It is no problem when the innovations of a company make it reliant on one or two suppliers.	2.29	0.934	2.27	0.885	2.74	0.970
A6. It is no problem when the innovations of a company make it reliant on one or a few customers.	2.29	0.900	2.25	0.885	2.82	1.00
A7. It is no problem when a company depends on high skilled, difficult to find employees.	2.41	0.938	2.41	0.994	2.78	0.997

Source: authors' own research.
AS pre = Attending Students pre-test; AS post = Attending Students post test; NAS = Non Attending Students

Table 4. Awareness of Black Swans

	AS pre	Standard Deviation	AS post	Standard Deviation	NAS	Standard Deviation
B1. It is no problem when a company ignores threats to its existence which are difficult to quantify.	1.84	0.738	1.84	0.830	1.97	0.894
B2. It is no problem when a company ignores low probability threats	2.45	0.973	2.14	0.887	2.45	1.08
B3. A company should take unlikely disasters into consideration in crisis management.	3.62	0.856	3.50	0.857	3.40	1.02
B4. Companies can neglect low probability threats in their risk management.	2.67	1.00	2.68	1.08	2.85	1.03

Source: authors' own research
AS pre = Attending Students pre-test; AS post = Attending Students post test; NAS = Non Attending Students

5. Conclusion

The research focuses on 1) the impact of the teaching intervention on students' perceptions, and 2) Differences in perception between non-attending (N = 128) and attending students (pre-test N = 139; post-test N = 119). Hypothesis 1 was confirmed, as hardly any significant teaching effect has been observed. This may imply that in-depth assignments and system approaches are rather necessary for a change in perceptions (Platje et al. 2019; Ng, Burke 2010; Beck 2017), and messages have to be repeated in order to be understood.

However, significant differences were observed between attending students and non-attending students. While this result should be treated with care, as it only concerns one case study of a specific group of students. It may imply that while teachers can do in-depth exercises and provide lectures, a part of the students is

unlikely to grasp sustainability issues, when not included in assignments, examination preparation, or compulsory rather than elective courses. In other words, the success of a teaching approach is likely depending on the approach in the course/curriculum, as well as the motivation of students (compare Molho 1997), an issue which needs more attention and deeper research.

References

Amyotte P., Margeson A., Chiasson A., Khan F. (2014), There is no such a thing as a Black Swan process incident, Hazards 24 Institution of Chemical Engineers Symposium Series, 7–9 May 2014, Edinburgh, pp. 12–21 [non refereed conference paper].

Alvesson M., Spicer A. (2012), A stupidity-based theory or organizations, "Journal of Management Studies", vol. 49 no. 7, pp. 1186–1220.

Beck H. (2017), Irren ist nützlich, Carl Hausner Verlag, München.

Becker G.S. (2009), Human capital: a theoretical and empirical analysis, with special reference to education, University of Chicago Press, Chicago.

Bertoncel T., Erenda I., Pejić Bach M., Roblek V., Meško M. (2018), A managerial early warning system at a smart factory: an intuitive decision-making perspective, "Systems Research and Behavioral Sciences", vol. 35 no. 4, pp. 406–416.

Bessant S.E., Robinson Z.P., Ormerod R.M. (2015), Neoliberalism, new public management and the sustainable development agenda of higher education: history, contradictions and synergies, "Environmental Education Research", vol. 21 no. 3, pp. 417–432.

Caniëls M.C., Lambrechts W., Platje J., Motylska-Kuźma A., Fortuński B. (2021), 50 shades of green: insights into personal values and worldviews as drivers of green purchasing intention, behaviour, and experience, "Sustainability", vol. 13 no. 8, art. 4140.

Carson K. (2002), The Iron Fist behind the Invisible Hand: corporate capitalism as a system of state-guaranteed privilege, Red Lion Press, Nanaimo, BC.

Casti J.L. (2013), X-Events – complexity overload and the collapse of everything, Harper Collins Publishers, New York.

Craven G. (2010), What's the worst that could happen? A rational response to the climate change debate, Perigee Book by Penguin Group, New York.

Elkington J. (2018), 25 years ago I coined the phrase "triple bottom line". Here's why it's time to rethink it, Harvard Business Review, vol. 25, pp. 2–5.

Gladwin T.N., Kennelly J.J., Krause T.S. (1995), Shifting paradigms for sustainable development: implementations for management theory and research, "Academy of Management Review", vol. 20 no. 4, pp. 874–907.

Harari Y.N. (2015), Sapiens: a brief history of humankind, Harper, New York.

Jacobs J. (1986), Cities and the Wealth of Nations – principles of economic life, Pelican Books, New York.

Jevons W.S. (1906), The coal question: an inquiry concerning the progress of the nation, and the probable exhaustion of our coal-mines, Macmillan, London.

Kahneman D. (2011), Thinking, fast and slow, Penguin Books, London.

Kochanowicz J. (2004), Trust, confidence, and social capital in Poland: a historical perspective, in: Trust and democratic transition in post-communist Europe, Markova I. (ed.), British Academy, Oxford, pp. 63–84.

Lambrechts W., Van Petegem P. (2016), The interrelations between competences for sustainable development and research competences, "International Journal of Sustainability in Higher Education", vol. 17 no. 6, pp. 776–795.

Lambrechts W., Van Liedekerke L., Van Petegem P. (2018a), Higher education for sustainable development in Flanders: balancing between normative and transformative approaches, "Environmental Education Research", vol. 24 no. 9, pp. 1284–1300.

Lambrechts W., Ghijsen P.W.T., Jacques A., Walravens H., Van Liedekerke L., Van Petegem P. (2018b), Sustainability segmentation of business students: toward self-regulated development of critical and interpretational competences in a post-truth era, "Journal of Cleaner Production", vol. 202, pp. 561–570.

Levin K., Cashore B., Bernstein S., Auld G. (2012), Overcoming the tragedy of super wicked problems: constraining our future selves to ameliorate global climate change, "Policy Sciences", vol. 45 no. 2, pp. 123–152.

Linton T., Vakil B. (2020), Coronavirus is proving we need more resilient supply chains, "Harvard Business Review", 5 March 5, https://hbr.org/2020/03/coronavirus-is-proving-that-we-need-more-resilient-supply-chains [22.09.2022].

Watson M.K., Lozano R., Noyes C., Rodgers M. (2013), Assessing curricula contribution to sustainability more holistically: Experiences from the integration of curricula assessment and students' perceptions at the Georgia Institute of Technology, "Journal of Cleaner Production", vol. 61, pp. 106–116.

Mandelbrot M., Hudson R.L. (2008), The (mis)behaviour of markets, Profile Books, London.

Mitchell A.S., Lemon M., Lambrechts W. (2020), Learning from the Anthropocene: adaptive epistemology and complexity in strategic managerial thinking, "Sustainability", vol. 12 no. 11, art. 4427.

Molho I. (1997), The economics of information – lying and cheating in markets and organizations, Blackwell Publishers, Oxford.

Ng E.S., Burke R.J. (2010), Predictor of business students' attitudes toward sustainable business practice, "Journal of Business Ethics", vol. 95 no. 4, pp. 603–615.

Novo-Corti I., Badea L., Mihaela Tirca D., Aceleanu M.I. (2018), A pilot study on education for sustainable development in the Romanian economic higher education, "International Journal of Sustainability in Higher Education", vol. 19 no. 4, pp. 817–838.

Meadows D. (1999), Leverage points – places to intervene in a system, The Sustainability Institute, Hartland.

Nussbaum M.C. (2010), Not for profit: why democracy needs the humanities, Princeton University Press, Princeton, NJ.

Platje J. (2019), The capacity of companies to create an early warning system for unexpected events – an explorative study, in: Lecture notes in computer science, Nguyen N.T. et al. (eds.), TCCI XXXIV, LNCS 11890, Springer, Heidelberg, pp. 1–16.

Platje J., Will M., Van Dam Y. (2019), A fragility approach to sustainability – researching effects of education, "International Journal of Sustainability in Higher Education", vol. 20 no. 7, pp. 1220–1239.

Platje J., Zepeda Quintana D.S. (2019), Business sustainability and early warning systems, in: Encyclopedia of sustainability in higher education, Leal Filho W. (ed.), Springer Nature Switzerland.

Raiser M. (1997), Informal institutions, social capital and economic transition: reflections on a neglected dimension, EBRD Working Paper 25, London.

Raiser M. (1999), Trust in transition, EBRD Working Paper 39, London.

Rao P.K. (2000), Sustainable development – economics and policy, Blackwell Publishers, Oxford.

Rittel H.W.J., Webber M.M. (1973), Dilemmas in a general theory of planning, "Policy Sciences", vol. 4, pp. 155–169.

Schumpeter J.A. (1942), Socialism, capitalism and democracy, Harper and Brothers, New York.

Smith A. [1776] (1998), An inquiry into the nature and causes of the wealth of nations, reprint edited with an introduction by Kathryn Sutherlands, Oxford University Press, Oxford.

Sterman J.D. (2000), Business dynamics: system thinking and modelling for a complex world, Irwin / McGraw Hill, Boston.

Taleb N.N. (2007), *The Black Swan – the impact of the highly improbable*, Penguin Books, London.

Taleb N.N. (2012), *Antifragile – things that gain from disorder*, Penguin Books, London.

Taleb N.N., Read R., Douady R., Norman J., Bar-Yam Y. (2014), The Precautionary Principle: fragility and black swans from policy actions, Extreme risk initiative – NYU School of Engineering Working Paper Series, https://arxiv.org/pdf/1410.5787.pdf [22.09.2022].

Trzeciak S., Rivers E.P. (2003), Emergency department overcrowding in the United States: an emerging threat to patient safety and public health, "Emergency Medicine Journal", vol. 20 no. 5, pp. 402–405.

Wright T.S.A. (2007), Developing research priorities with a cohort of higher education for sustainability experts, "International Journal of Sustainability in Higher Education", vol. 8 no. 1, pp. 34–43.