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Stress Relief Exercises

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Abstract: In March 2022, Jamais Cascio—author and global thinker—introduced the "BANI" model, an acronym that stands for Brittle, Anxious, Non-linear, and Incomprehensible. These terms capture the nature of today's world, where changes are not only unexpected but often deeply disorienting. Such a reality has a profound impact on our mental and physical health. We are constantly told to "live an organized life, eat well, get enough sleep... and ... don't stress..." However, the real question remains: what can we do to reduce stress immediately? There are many possible strategies. In this brief overview, we will focus on three simple and effective exercises.

Keywords: stress, diaphragmatic breathing, self-administered acupressure, aromatherapy

1 Stress

Prof. Dr. Hans (János) Selye (1907–1982) is widely recognized as the founding father of the concept of **general adaptation syndrome**, commonly known as **stress**. He famously stated, "*Stress is the spice of life*" (Selye, 1936; Siang Yong Tan, 2018).

Stress refers to the body's non-specific response to any demand or challenge—whether physical, mental, or emotional. It triggers a cascade of physiological changes, such as increased heart rate and the release of stress hormones, in order to prepare the body to cope with the situation. In essence, stress is the body's natural mechanism for adapting to internal or external demands. Importantly, stress can be beneficial and even essential, as it activates the "**fight or flight**" response—a survival mechanism that enhances our ability to respond to threats or challenges. This response is regulated by the **autonomic nervous system**, which consists of two branches: the **sympathetic** and **parasympathetic systems**. Together, these systems control involuntary physiological functions essential for maintaining homeostasis. (See Figure 1.)

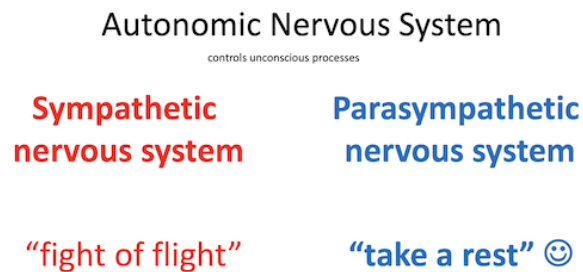


Figure 1.
The two parts of the Autonomic Nervous System

1.1 Response to Stress and the BANI Model

During stressful situations, an increase in sympathetic nervous system activity is characterized by elevated heart rate and arterial blood pressure, as well as heightened blood levels of the hormones adrenaline and cortisol. This state of heightened physiological arousal enhances our ability to respond effectively to immediate challenges, such as avoiding danger or meeting pressing deadlines (Bern & Levy, 2010). While short-term stress can be beneficial in such contexts, excessive or chronic stress can have detrimental effects. Maintaining an appropriate balance is essential — insufficient stress may result in a lack of motivation, whereas excessive stress can become overwhelming (Hutmacher et al., 2021).

In contemporary life, individuals frequently encounter numerous stress-inducing situations. In March 2022, author and futurist Jamais Cascio introduced the "BANI" model, an acronym that stands for Brittle, Anxious, Non-linear, and Incomprehensible (Cascio, 2020). These four descriptors offer a compelling framework for understanding the complex, unpredictable nature of the modern world.

2 Three Stress Relief Exercises

There are numerous approaches to alleviating stress, and it is likely that each individual has developed personal strategies that they find effective. In this brief overview, we will focus on three straightforward techniques commonly employed for stress reduction:

1. **Slow, deep abdominal breathing**
2. **Self-administered stimulation of specific acupuncture points on the body**
3. **Inhalation of a personally pleasant natural essential oil (commonly referred to as aromatherapy)**

Each of these methods exerts modulatory effects on the autonomic nervous system, typically by attenuating sympathetic nervous activity while enhancing parasympathetic responses. The net physiological outcome is a measurable reduction in stress levels.

2.1 Slow, Deep "Abdominal" (Diaphragmatic) Breathing

Regular breathwork practices have increasingly been recognized as effective interventions for stress reduction and the promotion of psychological well-being. This is largely due to the influence of respiratory activity on several brain regions involved in the regulation of cognition, behavior, and emotion (Balban, 2023; Ficham, 2023). Empirical studies on healthy individuals have demonstrated that slow, controlled breathing—specifically at a rate of approximately six breaths per minute—is associated with favorable physiological outcomes, such as reduced blood pressure, when compared to typical respiratory rates of 12 to 16 breaths per minute (Bernardi et al., 2001; Chang et al., 2013; Zhang et al., 2016).

A wide variety of breathing exercises exist, each with its own approach and emphasis. The following technique, personally practiced by the author, exemplifies a simple yet effective method for diaphragmatic breathing:

Mental Preparation: Commit to focusing exclusively on your breathing for the next five minutes.

Posture: The exercise can be performed while standing, seated, or lying on your back. Place one hand on the center of your chest and the other on your abdomen.

Controlled Breathing Sequence:

Inhalation: Breathe in slowly through the nose (mouth closed), allowing the abdomen to expand like a balloon. Feel it gently press into your hand. Count to four silently during the inhalation.

Breath Retention: Hold the breath for a mental count of four.

Exhalation: Exhale slowly through the nose (mouth still closed) while gently contracting the abdominal muscles. Count to six silently during exhalation.

Post-Exhalation Pause: Hold the breath again for a mental count of four.

Repeat this cycle continuously for a duration of five minutes (Ling, 2023).

A substantial body of research supports the efficacy of slow, deep abdominal breathing in reducing stress and promoting relaxation (Hamasaki, 2020; Magnon et al., 2021; Hunt et al., 2021; Birdee et al., 2023; Tavoian et al., 2023).

2.2 Self-Administered Massage of Specific Acupuncture Points on the Body Surface

2.2.1 Historical and Theoretical Background

Traditional Chinese Medicine (TCM) has a history spanning over 5,000 years. It is founded on a holistic worldview that emphasizes harmony between humans and nature. As defined by Ma et al. (2021), "Traditional Chinese Medicine is a medical knowledge system developed by the Chinese people. It is characterized by a holistic approach that encompasses image-based information processing, cognitive activity based on attributes and relationships, the utilization of natural resources both within and outside the human body, and the regulation and balancing of health status."

TCM serves not only as a framework for disease prevention, diagnosis, and treatment but also for rehabilitation and health maintenance. It is primarily derived from natural medicinal sources, including herbal, animal, and mineral substances, as well as certain chemical and biological products (Ma et al., 2021).

The terminology used in TCM originates from classical Chinese, and many of its concepts differ significantly in meaning from those used in contemporary Western medicine (Wang & Chen, 2023). Fundamental philosophical constructs such as *Qi* (vital energy), *Yin and Yang*, and the *Five Elements* (Wood, Fire, Earth, Metal, Water) form the theoretical basis of TCM (Huang Di Nei Jing, English translation 1990).

The concept of *Qi* (氣, pronounced "chee") is central to TCM but remains difficult to translate precisely. For the purposes of this discussion, it can be understood as a form of "vital energy" that flows throughout the body. According to *Huang Di Nei Jing* [黄帝内经] (The Yellow Emperor's Inner Canon), widely considered the oldest extant medical text in the world, the human body is traversed by a network of meridians—pathways that interconnect internal organs with the limbs, head, and skin surface. These meridians facilitate the flow of *Qi*, which is believed to be more concentrated along these channels. Along the meridians lie 365 classical acupuncture points, along with numerous "extra-meridian" points not associated with a specific meridian. TCM

posits that imbalances or blockages in the flow of *Qi* lead to disease and dysfunction, and that stimulation of acupuncture points can help restore internal equilibrium.

Each acupuncture point is identified by a Chinese name and a standardized alphanumeric code. For example, "Shen Men" (Spirit Gate) is designated as HT7, indicating that it is the seventh point on the Heart meridian. The Latin abbreviation preceding the number refers to the associated meridian or, in some cases, indicates that the point lies outside (EXT) the established meridian system.

Definitions:

Acupuncture: A therapeutic technique in TCM involving the insertion of fine needles into specific points on the body to influence the flow of *Qi* and restore balance.

Acupressure: A non-invasive TCM therapy that involves applying manual pressure—typically with the fingers—to specific acupuncture points to achieve similar therapeutic effects as acupuncture.

2.2.2 Effects of Acupressure and Acupuncture on the Human Body

The precise mechanisms underlying the physiological effects of acupuncture and acupressure remain incompletely understood. Several hypotheses have been proposed, including modulation of the autonomic nervous system, regulation of neurochemical mediators, and enhancement of local blood circulation. Despite the lack of complete mechanistic clarity, interventions at specific acupuncture points have been shown to induce measurable physiological responses. In numerous cases, these responses have been scientifically demonstrated to exert beneficial effects on human health (Cabioglu, 2016). A comprehensive meta-analysis by Li et al. (2024), which reviewed 700 publications on acupressure, concluded that "acupressure has proven efficacy in symptom management, making it valuable in clinical practice and patient care."

Ongoing research continues to explore the mechanisms and therapeutic potential of acupuncture and acupressure (Sato, 1997; Shan et al., 2014; Ma, 2020; Liu et al., 2021; Hutsalenko et al., 2022; Sun & Chen, 2022; Wang & Chen, 2023; Larki et al., 2025; Liu Y. et al., 2025). These studies contribute to a growing body of evidence supporting the clinical application of these traditional techniques within integrative medicine.

2.2.3 World Health Organization (WHO) Position on Traditional Chinese Medicine (TCM)

The World Health Organization (WHO) recognizes Traditional Chinese Medicine (TCM) as a complementary and alternative therapeutic approach for the treatment and management of certain symptoms and health conditions. Over the years, WHO has systematically addressed the role of TCM through a series of guidelines and strategic

documents aimed at integrating traditional medicine into national health systems in a safe, effective, and evidence-based manner (WHO, 1999; WHO, 2021; WHO, 2022; WHO, 2025).

2.2.4 Mechanisms of Acupressure in Acute Stress Reduction

Self-administered acupressure applied to specific acupuncture points on the body has been found to be effective in reducing acute stress levels. A plausible physiological explanation is that stimulation of certain somatic sites may enhance parasympathetic nervous system activity within the autonomic nervous system. While the exact neurobiological mechanisms remain incompletely understood, it is hypothesized that acupressure may promote a relaxation response through modulation of vagal tone or central autonomic networks.

2.2.5 Acupuncture Points Commonly Used to Alleviate Stress

Traditional Chinese Medicine (TCM) identifies numerous acupuncture points that, when stimulated through massage, may contribute to the reduction of stress. Among these, three specific points have been selected for discussion due to their accessibility, safety, and frequent citation in the literature as effective sites for stress relief. These points are relatively easy for individuals to locate and apply pressure to, making them practical for both clinical and self-care applications.

2.2.5.1 Yintang (“Hall of Impression”) [EXT-2]

This acupoint is located precisely at the midpoint between the medial ends of the two eyebrows. It can be identified by locating the exact center between the brows (Jaung-Geng Lin, *Atlas of Acupunturology*, 2023) (Figure 2).



Figure 2.
Yintang = "Hall of Impression" (EXT-2)

2.2.5.2 Shenmen (“Spirit Gate”) [HT7]

Located on the ulnar side of the wrist, posterior to the palm, Shenmen lies in the depression distal to the prominence of the pisiform bone and at the level of the wrist crease, adjacent to the head of the ulna (Jaung-Geng Lin, *Atlas of Acupuncturology*, 2023) (Figure 3).



Figure 3.
Shenmen = “Spirit gate” (HT7.)

2.2.5.3 Taiyuan (“Great Abyss”) [LU9]

Taiyuan is found on the radial aspect of the wrist, at the level of the transverse wrist crease. It is located in the depression between the radial artery and the tendon of the abductor pollicis longus muscle—where the radial pulse is typically palpated (Jaung-Geng Lin, *Atlas of Acupuncturology*, 2023) (Figure 4).



Figure 4.
Taiyuan = “Great Abyss” (LU9.)

2.2.5.4 Remarks

The aforementioned acupoints are often reported to be slightly more sensitive to pressure than surrounding tissue in many individuals, although the underlying mechanisms are not fully understood.

Recommended acupressure technique:

* **Stimulation method:** Apply circular pressure using the fingertip in a gentle, clockwise motion. The pressure should be firm enough to be distinctly perceptible but not painful.

* **Order of application:** Always begin wrist point stimulation on the **left wrist**.

* **Duration:** Each point should be massaged for approximately **3 to 5 minutes**.

2.3 Inhalation of Natural Essential Oils Considered Pleasant (“Aromatherapy”)

The potential therapeutic effects of natural essential oils on human health have garnered increasing scientific interest over the past two decades. This area of research and clinical application is commonly referred to as *aromatherapy* in the scientific literature.

2.3.1 Anatomical and Physiological Background

Olfaction is considered the most evolutionarily ancient of the human senses. The human olfactory system, located at the upper part of the nasal cavity, comprises a dense array of olfactory receptors. These receptors are responsible for detecting volatile chemical compounds (odorants) and converting them into neural signals. Upon binding specific odor molecules, the olfactory receptors stimulate olfactory sensory neurons, which are in direct contact with the olfactory bulb—a structure situated at the base of the brain. From the olfactory bulb, information is rapidly transmitted to several regions of the brain, most notably the limbic system. The limbic system plays a key role in the regulation of emotions, memory, and autonomic (vegetative) functions. This direct neuroanatomical connection explains the immediate and profound influence of scents on emotional states and physiological responses (Pizzolo SFM et al., 2021).

2.3.2 Inhalation of Selected Essential Oils for Stress Reduction

Essential oils are volatile, aromatic compounds extracted from various parts of plants, including flowers, bark, roots, and leaves. These compounds are typically stored in specialized cells and serve biological functions within the plant (Steflitsch & Steflitsch, 2008). In recent years, numerous essential oils have been investigated for their potential to alleviate stress and promote relaxation through inhalation.

Lavender (*Lavandula angustifolia*) is among the most extensively studied essential oils for its anxiolytic and stress-reducing properties. Empirical evidence indicates that inhalation of lavender essential oil can significantly reduce heart rate and blood pressure, contributing to lower levels of psychological and physiological stress (Chen et al., 2015; Yoo & Park, 2023).

Chamomile (*Chamaemelum nobile*), particularly Roman chamomile, has also demonstrated promising effects in reducing stress and anxiety. Its mild sedative

properties may contribute to an overall calming effect, supporting its traditional use in managing stress-related symptoms (Pourshaikhian et al., 2024).

Bergamot (Citrus bergamia) essential oil has been associated with mood enhancement and decreased levels of anxiety. Several studies suggest that bergamot may reduce cortisol—the primary stress hormone—thereby alleviating emotional stress. Wakui et al. (2023) reported that “using bergamot essential oil before bedtime helps relax the mind and body and provides sound sleep. It also improves mood and wakefulness when used upon awakening. Using aromatic essential oils is expected to relieve psychological stress and improve sleep quality and morning wakefulness.”

Vora et al. (2024) conducted a comprehensive review of the literature and concluded: “Aromatherapy combines traditional and contemporary medicine, offering holistic healing with essential oils. Through complex interactions, essential oils modulate health, influencing mood, comfort, and overall well-being.”

In addition to these well-known oils, several other essential oils have shown potential in stress reduction, although individual responses may vary based on physiological and psychological sensitivity. Some studies have reported greater efficacy among female participants compared to males. Research in this field continues to evolve, with ongoing studies aimed at better understanding the mechanisms and efficacy of essential oils in stress management. (Huang et al., 2016; Sharma et al., 2019; Xiao et al., 2023; Saiyudthong et al., 2025).

2.3.3 Practical Considerations

For individuals interested in experimenting with this approach, the following guidelines should be carefully considered:

- * Only natural essential oils, preferably those obtained from reputable sources such as pharmacies, should be used. Synthetic alternatives may contain additives or impurities that could pose health risks.
- * Inhalation should be limited to one or two brief sniffs per session to minimize the risk of overstimulation or adverse effects.
- * This method is not recommended for individuals with a known history of allergic reactions, such as seasonal allergic rhinitis (hay fever), due to the potential for triggering hypersensitivity responses.

Conclusion

A variety of strategies exist for mitigating stress, among which simple, non-invasive techniques can offer accessible and effective relief. This overview focused on three such methods: (1) slow, deep abdominal breathing; (2) self-administered acupressure at three specific acupuncture points; and (3) inhalation of a personally pleasant natural

essential oil, commonly referred to as aromatherapy. Each of these interventions has been shown to modulate autonomic nervous system activity by attenuating sympathetic arousal and enhancing parasympathetic tone. The resultant shift in autonomic balance contributes to a measurable reduction in stress levels.

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Harvesting Intelligence: A Conceptual AI Framework for Precision Irrigation

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Abstract: Efficient water resource management is paramount for sustainable agriculture amidst increasing global population and climate variability. This paper establishes a novel theoretical framework for an AI-driven Decision Support System (DSS) specifically designed to enhance precision irrigation practices. The primary aim of this investigation is to leverage this framework to develop a deep learning AI model capable of accurately predicting and precisely detecting water stress sections within crops of interest, thereby enabling highly targeted and efficient water applications. The proposed framework integrates multiple heterogeneous data sources to construct a comprehensive spatio-temporal understanding of crop water status. It includes Earth Observation (EO) data from Sentinel-2 B satellites, specifically utilizing vegetation indices such as Normalized Difference Vegetation Index (NDVI) for assessing vegetation health and Normalized Difference Moisture Index (NDMI) for soil water content. Complementing this, high-resolution in-situ measurements are collected by IoT sensors (e.g., IoT-NPK for soil moisture, NPK levels, temperature, and pH) mounted on mobile robot platforms like PlatypOUs, providing essential ground truth validation. Furthermore, meteorological data, i.e., precipitation, air, and soil humidity, is integrated to provide crucial environmental context and predictive insights. This paper outlines a methodology for developing a Recurrent Neural Network (RNN) architecture based on a U-Net topology that will effectively encode features from these integrated data streams. The model incorporates multiple convolution layers for efficient spatial feature extraction, Long Short-Term Memory (LSTM) layers to capture temporal dependencies, and attention layers to focus on the most critical features for prediction. The ultimate output is a newly generated image representing the predicted spatial distribution of water stress across the field of interest, allowing pixel-based classification for targeted irrigation recommendations. This foundational investigation, including initial data analysis and feature engineering, paves the way towards optimized water use, significantly improving agricultural productivity and enhancing resource conservation.

Future research will focus on this advanced AI model's rigorous development, training, and validation.

Index Terms: Water sustainability, Precision Farming, Artificial Intelligence, Human operator support, Mobile Robot Platforms, IoT.

1 Introduction

The increasing global population and changing climate patterns place unprecedented demands on water resources, particularly in the agricultural sector, which accounts for a significant portion of freshwater consumption [1]. Thus, efficient management of water resources is crucial to ensure sustainable agricultural productivity and global food security [2]. Traditional irrigation practices often lead to water wastage due to inefficient distribution and a lack of precise information on crop water requirements [3]. Therefore, there is a growing need for innovative approaches to optimize water use, improve crop yields, and minimize environmental impact.

The health and productivity of crops are intricately linked to the availability of essential nutrients, including nitrates (N), phosphates (P), and potassium (K) [4]. These macronutrients play vital roles in various physiological processes such as photosynthesis, nutrient transport, and root development [5]. Monitoring their levels in the soil is crucial to optimize fertilization and irrigation strategies [6]. In addition, Earth Observation (EO) systems provide valuable data for land cover classification [7], [8], which is essential to understand the spatial distribution of different types of vegetation and their water requirements. Classifying land cover makes it possible to identify areas with similar hydrological characteristics and tailor irrigation management accordingly.

Satellite sensors offer a powerful means to assess vegetation conditions and water stress [9]. The Normalized Difference Vegetation Index (NDVI) is a widely used index that measures the greenness of vegetation and is related to photosynthetic activity and biomass [10]. On the other hand, the Normalized Difference Moisture Index (NDMI) is sensitive to the water content of vegetation and soil [7]. These indices, derived from multi-spectral imagery acquired by satellites, i.e., Sentinel-2 A/B, provide valuable information on crop water status's spatial and temporal variability [8], [11].

Although EO provides a broad overview, in situ data collection is essential to capture variations at higher resolution and validate satellite-based information [9]. For this reason, mobile robot platforms equipped with environmental sensors offer a flexible and efficient solution to collect real-time data on soil conditions [12], [13]. These robots can measure crucial parameters, e.g., soil moisture and temperature, at specific locations within the field to be studied [14], providing valuable data to calibrate and validate models of water stress.

This paper is part of the Water Resource Efficiency Network (WREN) project, which aims to enhance the spatial and temporal resolution of drought monitoring and improve site-specific management support for optimal irrigation and crop yield, combining remote sensing and local data, leveraging EO methods and AI techniques [8]. This paper proposes a conceptual framework for an AI-driven decision support system (DSS), which integrates EO data, in-situ measurements from IoT sensors and mobile robot platforms, and advanced machine learning techniques to predict crop water stress and optimize irrigation scheduling. Based on the U-Net model, the proposed system will leverage a Recurrent Neural Network (RNN) architecture to effectively encode relevant features from satellite images and in-situ data. This approach aims to provide accurate, site-specific irrigation recommendations, enhance water use efficiency, improve crop health, and promote sustainable farming practices.

2 Background and Related Work

2.1 Earth Observation and Precision Farming

Earth Observation (EO) has become an indispensable tool in modern agriculture, offering a wide range of applications for precision farming [3], [9]. EO data from satellite and aerial platforms provide valuable information on various crop and environmental parameters, enabling farmers to make informed decisions and optimize their management practices.

The research of Ferreira et. al. [15] suggested that the combination of Earth observation and machine learning was successfully applied in several different fields across the world. The implications of EO in precision farming are not excluded, as this data can be used for multiple purposes e.g., crop monitoring, water management, nutrient management, pest and disease management, yield prediction, estimating crop yields before harvest; and land cover classification [7], [3], [11].

Consequently, by providing timely and accurate information, EO helps farmers to improve input use efficiency, reduce environmental impact, and enhance crop productivity [16].

Vegetation indices (VIs) are quantitative measures derived from EO data that provide information about the biophysical properties of a field to be studied, as they are widely used to assess crop health, monitor growth, and detect stress [17]. The Normalized Difference Vegetation Index (NDVI) is used to measure the difference between near-infrared (NIR) and red light reflected by vegetation, as healthy vegetation reflects more NIR light and absorbs more red light, resulting in high NDVI values, while low NDVI values indicate sparse or stressed vegetation [18].

On the other hand, the Normalized Difference Moisture Index (NDMI) is another important VI sensitive to vegetation water content. It uses the difference between NIR and shortwave infrared (SWIR) reflectance. SWIR is sensitive to water in plant canopies, so NDMI can help estimate crop water status and detect water stress [7].

Other VIs, such as the Enhanced Vegetation Index (EVI) and the Soil-Adjusted Vegetation Index (SAVI), are also used in agriculture to account for atmospheric effects and soil background, respectively, making them a good option to extract relevant characteristics to estimate crop water content [17].

Previous research has demonstrated the potential of EO and Artificial Intelligence (AI) to improve agricultural water management. For instance, [7] found a correlation above 90% between soil moisture values estimated from satellite images (using NDMI) and ground-truth moisture lectures based on the OPTRAM model, highlighting the effectiveness of EO in capturing soil moisture variations.

2.2 Mobile Robot Platforms in Precision Farming

In addition to EO data, real-time information on soil conditions is crucial for precision farming [8]. Soil parameters such as N, P, K levels, temperature, moisture, and pH can vary significantly within a field, affecting crop growth and yield [6], [4].

Sensors with ion-selective electrodes (ISEs) are devices that measure the activity of specific ions in a solution [19]. For this reason, this method can be used to determine the concentration of N, P, and K ions in the soil, providing a direct measure of nutrient availability to plants [20]. These electrodes are designed to selectively respond to their target ions, generating a potential difference proportional to the ion activity, which can then be converted into a measurable concentration using the Nernst equation 1 [19].

$$E = E^0 + \frac{RT}{nF} \ln(a_i) \quad (1)$$

where:

E is the measured potential, E^0 is the standard electrode potential, R is the ideal gas constant, T is the absolute temperature, n is the charge of the ion, F is the Faraday constant, a_i is the activity of the ion.

These sensors can be incorporated into Unmanned Vehicles (UV) as they can collect relevant soil information [13], providing a comprehensive understanding of its conditions throughout the field of study to optimize and validate water distribution models, fertilizer usage, irrigation scheduling, and other management practices.

Mobile robot platforms are increasingly being adopted in precision farming for various tasks, including in situ data collection [14]. As UVs can navigate through the field, this technology can significantly reduce the workload of farmers or researchers in several ways, being one of the motivations of this research.

2.2.1 The PlatypOUs Robot Platform.

The PlatypOUs robot (shown in Figure 1) is a differential drive mobile platform with two wheels on the front and a caster wheel on the back. Created by the Special College of Robotics of Obuda University [21]. The control system is based on the open-source ROS robotics middleware. The version used is Noetic [22], where a node has been created to receive a velocity input in a twist format to control the robot's position.

The robot has environmental sensors, including an IoT-NPK sensor, which measures soil moisture, NPK levels, temperature, and pH. Mobile robots like PlatypOUs streamlines the data collection process, improving the efficiency and accuracy of in situ measurements, which are crucial to generate accurate land cover maps, calibrate EO data, and train AI models to predict crop water stress.

2.3 AI in Precision Farming

AI is rapidly transforming the agricultural sector [2], with significant advances in water stress estimation and precision farming [3]. Machine learning algorithms, including deep learning techniques, are increasingly used to analyze complex agricultural data from various sources, including EO imagery, meteorological data, and in situ sensor measurements [5].

In water stress estimation, AI models are being developed to predict crop water requirements and detect drought conditions [23]. These models can identify patterns and relationships between different variables, such as vegetation indices, soil moisture, and weather parameters, to provide accurate and timely information on crop water status [24].

Artificial intelligence plays a crucial role in precision farming, allowing the development of site-specific management strategies [25]. Machine learning algorithms can be used to analyze data on soil properties, crop health, and environmental conditions to optimize the application of inputs such as water, fertilizers, and pesticides [23]. It increases efficiency, reduces costs, and minimizes environmental impact [16].

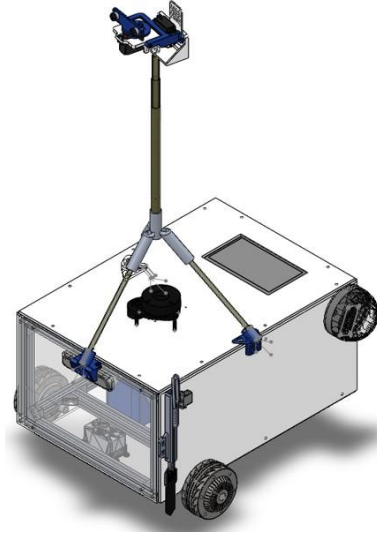


Figure 1
CAD representation of the PlatypOU's mobile robot platform

3 Methodology

The proposed methodology aims to analyze and integrate information from multiple data sources i.e. EO data (e.g. NDMI, NDVI), in-situ soil features' measurements, and weather stations information to train an AI in order to take part in a Decision Support System (DSS) for precision irrigation.

3.1 Field of Study

The land selected to be the subject of analysis is located in the region of Esztergom - Hungary (Csolnok), as shown in Figure 2.

3.2 Dataset acquisition and Pre-processing

3.2.1. Earth Observation Data. Multi-spectral images will be acquired from Sentinel-2 A/B satellites between January 2022 and May 2025. These images will be pre-selected based on the cloud cover percentage, where a threshold of 20% was set to discriminate relevant images considering the location of the field to be analyzed. Furthermore, vegetation indices, i.e. NDMI and NDVI will be calculated using equations 2 and 3,

respectively, based on the frequencies Near Infrared (NIR), Short Wave Infrared (SWIR), and Red (RED) captured by the satellite sensors.

$$NDMI = \frac{NIR - SWIR}{NIR + SWIR} \quad (2)$$

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (3)$$



Figure 2
Field of Study

As stated in section 2, Wojtaszek et. al. found a correlation above 90% between soil moisture values estimated from satellite images (using NDMI) and ground-truth moisture data [10]. These results strongly suggest that satellite imagery, more specifically, the NDMI and NDVI indexes, are ideal for providing relevant features to a deep learning model capable of predicting the state of water stress of the crop of interest [5], [14].

On the other hand, a shape based on the land geometry and location will be applied as a mask to create fix-sized images that contain only the information of the Field of Interest (FoI) to reduce noise and limit the amount of information that the deep learning model will process, therefore reducing the processing time [11], [15].

3.2.2 In-situ Data

Real-time data on soil conditions will be collected using IoT sensors mounted on a mobile robot platform. For research and development purposes, the PlatypOUS platform has been used to test the system integration, as the robot is equipped with an IoT-NPK sensor (see Figure 3) to measure soil moisture, NPK levels, temperature, and pH.

Once the data has been collected, an Inverse Distance Weight interpolation method will be applied to estimate the soil's moisture content across the entire FOI, to be used during the training and validation process of the deep learning model development [26].

3.2.3 Meteorological data

Weather data (i.e. precipitation, air and soil temperature, relative humidity, and soil moisture at different depths) will be collected from 121 available meteorological stations distributed throughout the country, as can be noticed in red dots inside the map of Figure 4.

The mentioned information is collected and stored in a csv file where each row contains the daily average of each variable sorted by station ID, opening the possibility of training a Random Forest Regressor model to predict future values on each one of the available stations.

The resultant dataset will be divided into two sub-sets: features (X) and targets (y). Both include all four selected variables, with the aim of predicting all variables based on their interdependence.

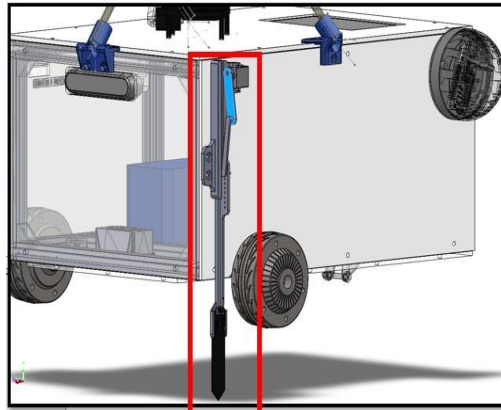


Figure 3
N-P-K Sensor

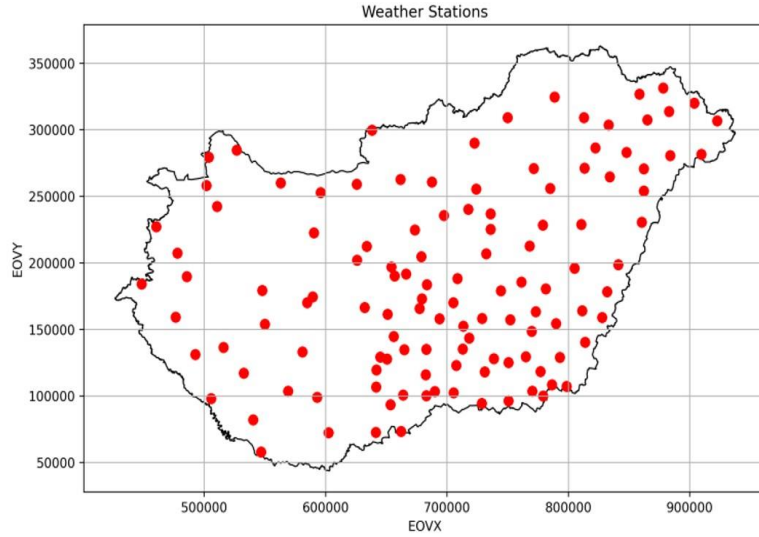


Figure 4
Spatial distribution of the available weather station across Hungary

Furthermore, the datasets will be normalized using the library *StandardScaler* [27] to normalize all features and target values between -1 and 1, ensuring they are on comparable scales to improve the model's performance.

The results of the Random Forest model predictions will be evaluated by comparing them with actual weather data, where metrics such as Mean Squared Error (MSE) and Root Mean Squared Error (RMSE) will assess the model accuracy [28].

3.3 Feature Engineering and Variable Selection

Random forests are known for their robustness and ability to handle large datasets with numerous variables. In this methodology, the model is hyper-parameterized using the library *GridSearchCV* to optimize performance, ensuring accurate predictions [29].

A set of four variables, i.e. *air temperature*, *soil temperature*, *soil moisture*, and *relative humidity*, was selected to be part of the prediction validation process; selection that was performed based on the author's considerations.

On the other hand, one of the features that Random Forest models offer is applied in this study where apart of a forecasting regression process, a relevance analysis will be performed to

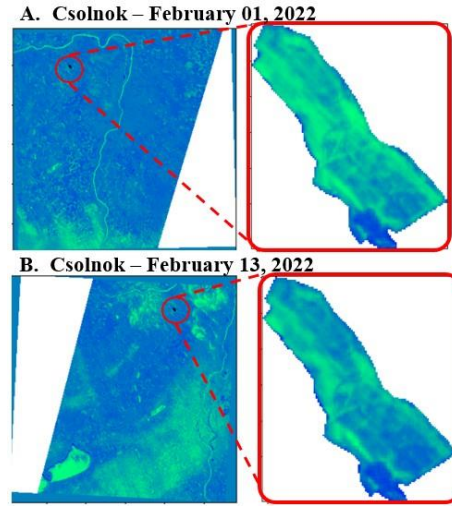


Figure 5
Satellite image pre-processing result

determine which of the preselected variables is the most relevant in weather forecasting [30], to be included as features in the proposed deep learning model.

4 Results

4.1 EO - Satellite images

Figure 5 shows two instances of the satellite image pre-processing, where A and B are the NDMI calculated per pixel before the region of interest is cut out while maintaining the geographic coordinates, and the respective normalized value, where the regions colored blue are the sections presenting more water stress.

4.2 Forecasted Variables

After training the Random Forest model based on the found hyper-parameters, it was used to predict the four selected variables for the test dataset (y). Predictions were scaled back to their original units using the inverse transform of the library StandardScaler [27]. The results were evaluated for each target variable, and the root mean square error (RMSE) was calculated as a measure of the accuracy of the prediction using equation 4.

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2} \quad (4)$$

where y_i and $\hat{y}_i$ are the real and the predicted values, respectively, and n is the total number of trials.

RMSE Results	
Variable Name	RMSE (%)
Air Temperature	1.25
Relative humidity	3.45
Soil Temperature	1.75
Soil Moisture	4.02

Table 1
Calculated rmse for the selected variables

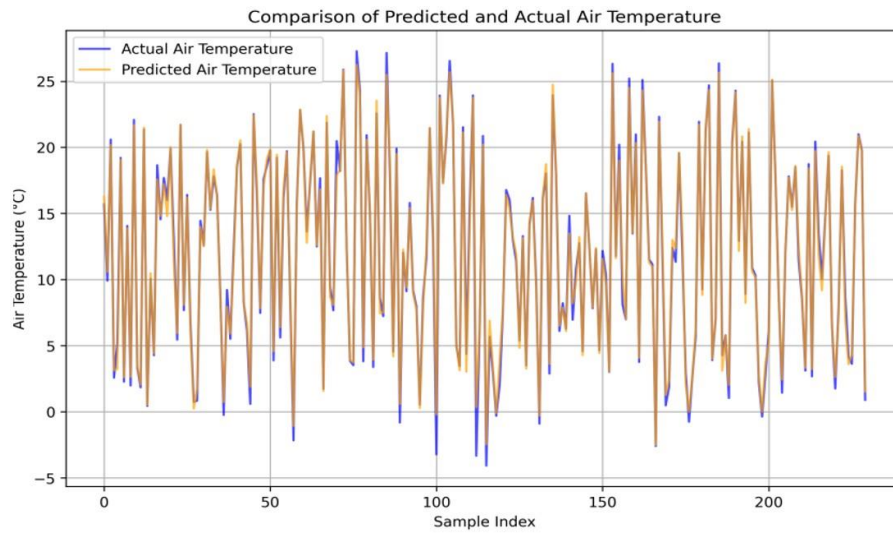


Figure 6
Predicted vs. Real values of one of the selected variables (Air Temperature)

Table 1 displays the resultant RMSE for each of the analyzed variables. In contrast, figure 6 compares the predicted and real data for the variable Air Temperature.

4.3 Variable Relevance Analysis

As section 3 mentioned, a Random Forest model was implemented to analyze the relevance of the available variables in terms of weather forecasting. As a result of the feature relevance analysis, it was identified that air and soil temperature were the most significant while predicting weather patterns from the selected dataset, as shown in Figure 7, underscoring their importance in agricultural modeling and suggesting that these variables should be included as features for the proposed AI model.

4.4 Discussion

The presented paper proposes a system framework to develop a DSS based on deep learning methods. It is RNNs that include convolution layers to encode relevant information, LSTM layers to retain time-relevant features into account to generate a prediction based on the

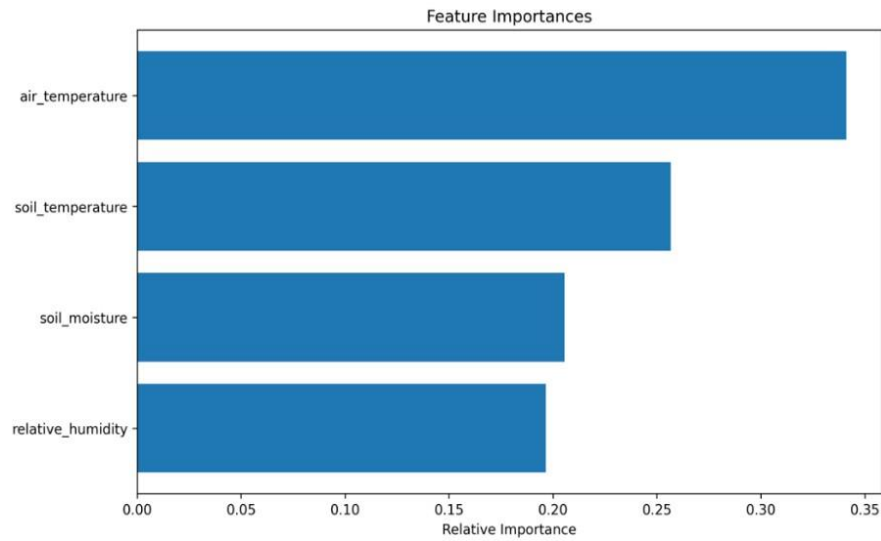


Figure 7
Results of the feature Relevance analysis

output of an attention layer before it is decoded to obtain a generated image representing the predicted state of the water stress distribution on the field of interest to be studied, providing the availability to suggest irrigation in the location where it is required, reducing the waste of the water resource during the irrigation process as it will be delimited to the area where it is required to prevent drought.

Although this proposal includes multiple relevant features from different data sources, it is notable that there is more information that should be considered in the DSS, as

underground water deposits and elevation levels, land cover maps, in order to obtain a water flow approximation that could prevent drought in crops.

5 Further Developments

5.1 AI Model Development and Validation

A Recurrent Neural Network (RNN) model will be developed to predict crop water stress based on the extracted features. The model will be trained using historical data and validated using independent data sets. The following Figure 8 shows a representation of the topology of the proposed model, Where can be notable the intention to use multiple convolution layers to encode the features presented in the post-processed satellite images while including the most relevant variables from the weather stations to posteriorly integrate a Long Short Term Memory layer (LSTM) to capture the relevance of the encoded data, to continue with an Attention layer to highlight the relevance of the most important features to be considered before a set of inverse convolutions are decoding the predicted information into a newly generated image based on the predicted values.

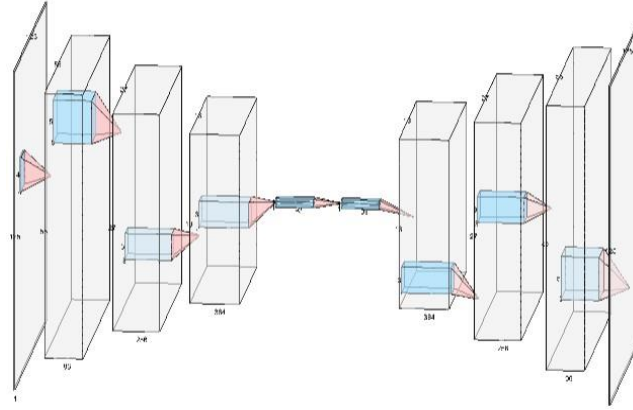


Figure 8.
Topological representation of the proposed Deep learning model

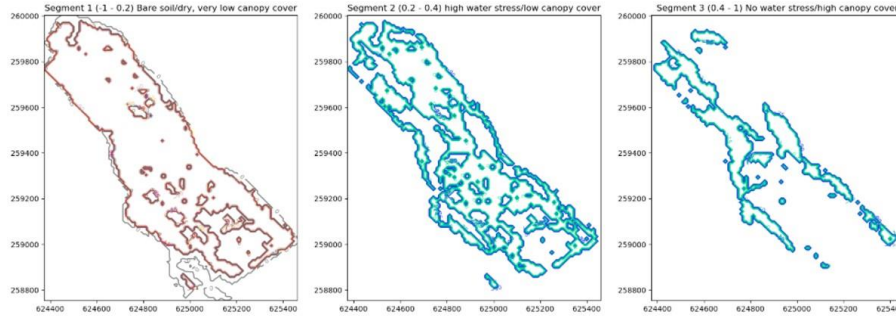


Figure 9
Example of the pixel-based classification

5.2 Decision Support System Development

A decision support system (DSS) will be developed to provide irrigation recommendations based on the model predictions.

The DSS will integrate data visualization tools and a user-friendly interface where the farmer will be notified where irrigation is required after applying a pixel-based classification, as the example in Figure 9 shows, where the range to determine the water-stressed sections was selected for demonstration purposes.

Conclusion

This paper successfully establishes a robust theoretical framework for an AI-driven Decision Support System (DSS) aimed at highly precise water stress detection and optimized irrigation management in agricultural settings. The feasibility and potential of this framework are underpinned by several key findings derived from the investigation.

Firstly, the research demonstrates the efficacy of integrating diverse, multi-modal data streams for a holistic understanding of crop water status. It This includes Earth Observation (EO) data, specifically the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI) derived from Sentinel-2 A/B satellites, which provide crucial insights into vegetation health and soil water content. Secondly, integrating high-resolution in-situ measurements collected by IoT-NPK sensors on mobile robot platforms like PlatypOUs, provides essential ground truth for soil moisture, NPK levels, temperature, and pH. Complementing these, comprehensive meteorological data from a network of weather stations offers critical environmental context and predictive insights. The successful preliminary analysis, including the validation of meteorological data forecasting with low RMSE values (e.g., 1.25% for air temperature, 1.75% for soil temperature) suggests that variables

such as air and soil temperature and humidity should be considered as features to take into account while training a deep learning model. On the other hand, satellite images can provide important information related to vegetation's health and soil water content by calculating the indexes NDVI and NDMI, respectively. The proposed deep learning topology includes convolution layers to encode information, an LSTM and Attention layer to perform a prediction, and inverse convolutions to generate an image based on the predicted features.

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The Third Mission of Higher Education Institutes and Their Potential Impacts

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Abstract: The object of this study is to clarify the definition of the third mission of higher education institutes with presenting this type of actions, furthermore, describing their possible impacts simultaneously. The paper does not aim to provide a full literature review of third mission activities. It is an important task to provide an insight into the evolving of the examined topic as well as outlining development directions and best practises for the higher education institutes through the reviewed literature between 2020 and 2024. The literature review ensures the theoretical framework in which the third missions of the higher education institutes can be understood, and its scope of activities be known with finding its relevance.

Keywords: third mission, higher education institute, university, region

1 Introduction

With the evolution of the knowledge-based economy and society, the operation of higher education institutions (HEIs) are becoming more valuable through their knowledge generating and sharing activities. The HEIs are under more pressure from both the EU and the national levels of Europe to participate in the tackling of different global and local problems. The new roles of HEIs are to contribute to solving these challenges and removing the barriers by giving effective responses.

In Hungary, the law, CCIV. Act of 2011. 2. § (5a), governing the National Higher Education includes the information about the higher educational institute, which says “the HEI through its core activities such as spiritual values for community purposes and economic utilization contributes to the social and economic development of its region” [1]. The role of the economic and social improvement of the higher education

with this Act was declared at the highest level of the regulatory hierarchy. The related chapter of Research, Development and Innovation Strategy of Hungary (2021-2030) dealing with the use of knowledge and the strengthening of the third mission activities of the universities was written as a top priority which includes the activities and the impacts of the HEIs on their environments [2]. The Documentation highlights the following areas requiring strengthening in order to fulfil their third missions such as the social engagement, promoting science, disseminating knowledge, creating and implementing the institutional SDG strategy, as well as the role of the regional innovational ecosystems, enhancing the cooperation with non-academic partners. Among the emphasized objectives of “Neumann János Program” governmental innovation strategy, approved in the 2023, are the strengthening of the knowledge-based economy through the universities and their partner economic actors [3]. The domestical HEIs are on the right track to develop in this area, which is clearly an expectation from the leaders of the higher education sector. Furthermore, the social, the economical and the environmental embeddedness of HEIs basically determine which development path they take during the creation of their course portfolio, establishing the physical infrastructure, choosing the scientific areas of the researchers, as well as the designing the base of the competencies and services [4]. The range of the third mission activities can develop based on the determination with which all the employees of the organisation have the leading role with their own attitudes, engagements for the place, the community through their personal responsibilities for the region through their employment.

With this study, we would like to contribute to the understanding of the HEIs third missions, get to know the range of their activities in this field, mostly with a literary review, in order to find the key points.

2 Method

We used the Scopus database to review the literature between 2020 and 2024 and as a result of this searching with these keywords (higher education institution, third mission, knowledge transfer, innovation, entrepreneur). We identified 46 occurrences. We chose the ones from this database query which could help this study to reach its goals. Besides that, we conducted another query of the database of Hungarian scientific publications (MTMT) which helped me to get information about the characteristics of the regions’ role of the HEIs.

The literature review was divided into these bigger parts: dealing with the regions’ role of the HEIs, and processes from the embedded state of the region as well as European and Asian examples with international perspectives, touching on the science parks, living labs, start-ups, furthermore the social responsibility and the issue of societal innovation.

3 Literature Review

We didn't find a universal definition for the third mission of the HEIs but rather they can say there is no such a thing because every HEI operation is a different framework that's why a unique embeddedness describes these organisations. With a general approach, we can say "it's about a complex, multidisciplinary, improving phenomenon" in which the relationship of the HEIs and the actors of every other sector will be completed in a way that is related to the social and economic mission, and it can be interpreted as a contribution to these fields [5]. Having examined the definition, we should mention the education and the research as the core activities of the HEIs. It is easier to define the content of the third one compared to the previously stated activities, the implementation of which gets special attention nowadays. Although there is no universal definition, there are some reoccurring topics, which provide the central scope of the analysis.

3.1 About The Regional Role of Higher Education Institutes

Firstly, we examined the supporting role of the of the HEIs in the regional economy through the domestic literary review. Imre Lengyel mentioned the serious problem coming from the geospatial location of the HEIs, which doesn't support the reducing of the territorial inequalities or even widens them. The author cited the Concept of the National Improvement and Regional Development in which the concentration of HEIs in the capital was established with the aim of strengthening the organisations located in the less developed regions. In his study, he noted that there are no locally based institutions in seven counties in Hungary, which can trigger a chain reaction such as reduction of the number of local students, shortages of professionals at the local economical actors, as well as the capabilities of the innovation and competitiveness. Thus, the regional supporting role of the economics of the HEIs couldn't be fulfilled [6]. Now we can find many examples which aim to strengthen the local higher education. We can mention, as a good example, the Training Centre and Research Site of Salgótarján (SKKK) which offers marketable degree to local students to facilitate the retaining power of their hometown with strengthening the local economy.

In the complex system of the sustainability, the authors draw attention to the importance of the fourth subsystem, for the innovation besides the classic pillars of the sustainability (economical – societal – environmental), however combined management is recommended during the regional developments [7]. The innovation should appear in the other subsystems to make the sustainability a reality by which process the societal marketing can have a key role [7]. The HEIs can participate in the social marketing as the third mission activities to provide the facts to as many people as possible in order to support the change of the paradigm and build a sustainable future through educational and awareness raising activities.

3.2 Relating To the Regional Embeddedness

The urban area, just as the city and its area, interpreted as one development region, was first mentioned in 2008 in one EU document along with functionality [8]. Since the determination was first used, the Functional Urban Area (FUA) have become one of the main tools of the development policy of the EU during the planning. When we want to define the FUA we can use the method of the EU-OECD: “The FUA consists of a city and its commuting zone and includes the economical and functional extent of the cities which is based on the daily movements of the people.” This definition was used for 33 OECD countries, as well as Columbia and the members of the EU [9].

The Hungarian urban areas mostly include the central towns of the counties, which function as a workforce catchment area and a hub of the region as well as the concentration point of the higher educational courses [6]. The efficient operation of the urban areas was reached with intermunicipal cooperations by harmonizing the developments and ensuring the size-optimal services in the functional urban areas [10].

As a result of the suburbanization effect of the urban area of Szekesfehervar’s demographics trends and labour market shift, the smaller towns (changing level) have achieved social gain in the number of residents and construction of new houses, furthermore the personal income tax have changed as this fact was highlighted by the author [8]. In the planning process of the public services and the institutional framework of the core town, people can be counted on to move away to become the population of the functional urban area and most of these people commute to work.

The universities function as a trigger institutions of multiplier effects for the local economy in their operational areas, and not just an education venue, but they have an impact on the improvement of the region by paying attention to the needs of the local labour market by designing their portfolio of courses to keep the youth in their hometown with marketable degrees [6]. They contribute to the increased capability of the foreign investments of the town and to the emergence of new economic organizations, employment opportunities by reacting to the feedback as fast as they can and cooperating in the local initiatives for the development of the town. The economic incentive force of the higher education institutes can be seen on the regional level by creating workplaces as an employer, by their investments in their infrastructure, and the contribution level of getting to know the region and branding the area [4]. As a result of the research, which contributed to the increasing acknowledgement of the region’s image, the authors drew attention to the value creating process of the higher education institutes and their stakeholders. The authors reached these results through examining the interacts of the three clusters: 1. knowledge transfer flow to the entrepreneurs; 2. co-creation and innovation within the HEIs; 3. third mission of the universities in the improvement of the entrepreneurial skills [11]. The authors investigated the third mission of the HEIs and the role of the creative and cultural sectors of the ecosystems which was based on the Quadruple Helix Model framework. In their study they found that the HEI plays a role in the

establishment of the ecosystem and as a builder of the capacity enhanced activities of working together which contributes to the creation of innovation and building the brand of the place [12].

3.3 International Examples of Good Practice Around Europe

In the United Kingdom data of 164 HEIs were analysed to find out how the organisations have fulfilled their third mission, furthermore whether they contribute to the development of the regions. The authors concluded that the additionality can be found in the support of the graduates, attracting foreign investments, promoting networking and in the R&D cooperations, but cannot be recognised in the support of SMEs and the process of the knowledge exchange [13]. Also in the UK, it was investigated how the changing learning role of the HEIs can affect the knowledge exchange activities and whether it influences the diversity or its strength. In their study the authors concluded that the HEIs need to meet that expectation, which says, on the one hand, they must contribute to the regional development along their third mission which can reshape the organisation's inner structure and operational order. On the other hand, they need to create a mission statement, which can be found credible by both external stakeholders and the internal employees, and it harmonises with represented values [14].

The needs of the fourth generation of the universities were brought up by the authors, based on the Oztel's idea, in which the teaming up with the relevant stakeholders appears in their operational social and economic space by aiming for sustainable growth [15]. In this model, actors operating in one region negotiate and cooperate in order to create values together for implementing a more sustainable future scenario.

Along the development of the theory of the third mission of the HEIs, the concept of the citizen university appeared next to the image of the entrepreneurial university, which first says to us that they disagreed with each other, since the first one is related to the entrepreneurial spirit, modernization, and focus on commercial utilization, while the second highlighted the social inclusion, where the institutions are the providers of the common goods and services. These two ideas were merged into a flexible and innovative way by the couple of authors in a hybrid form theory in which the focus is on the usage of the creative resources for the design of the new solutions [4].

While identifying the global trends with the enterprising universities that are integrated in the innovational ecosystem as supporters of different stakeholders with the image of the innovative HEI, the author highlighted the engagement of entrepreneurial approach in the third mission, the necessity of the lifelong learning and having an impact on society [16].

The German Educational and Research Ministry intended to motivate the society to take interactions, so they created the Innovative College program. The authors, within the program, established the "innovation saloon", which is one of the interactive and

dialogical approach aimed to urge civil society to take part in the third mission activities to solve societal challenges [17]. In this vision, the dialogical interpretation of knowledge transfer appeared which can be inserted into the innovation ecosystem of the HEIs. Also, another couple of German authors analysed activities of the third missions in order that they could create a framework for its definition. The results of their research showed that in the mission statements of the universities focus was placed on the economic issues, mostly concentrating on the technical knowledge transfer, social responsibility and the topic of upskill was not significant [18]. In Austria, under this collection of concepts of the third mission, the ongoing social innovations were processed in the HEIs. The authors, in the study aimed at getting to know the Austrian practices, found that the third mission activities of HEIs were divergent at that moment, but with the support of the senior leaders can be raised to a strategic and more visible level [19].

3.4 International Examples of Good Practice Around Asia

A couple of authors presented the kind of connections that are between the patterns of the knowledge exchange and the institutional types through an empiric example of the global city, Hong Kong [20]. In their study, they concluded that almost every state university of Hong Kong created their capabilities to support the implementation of the knowledge exchange process with non-academic actors.

In an Indonesian study, they researched how creating an entrepreneurial university model can be possible with this systematic approach (“direction of the future university”) while making sure that the development of the community is accelerated during the execution of the third mission activities. The authors highlighted that the HEIs need to participate more in the national development and the knowledge transfer for the acceleration of the economic growth in the community [21]. They came to the conclusion that the entrepreneurial university model might be a catalyst for starting new businesses and it can contribute to the boosting of economic growth and decreasing of the unemployment rate. The appearance of the entrepreneurial spirit and the education in the curriculums of the HEIs became an important precondition for innovation and technological improvement. Therefore, the path is clear via increasing the rates of the graduates to encourage implementation of further factors, for example: science and technology parks, patents etc.

From the perspective of the HEIs, the Indonesian researchers investigate how to create a Quadruple Helix Model within the actors through supporting innovations of sustainable, regional social-economic developments [22]. The authors of the study concluded that the implemented sustainable entrepreneurial culture simultaneously made the application of the entrepreneurial university model and the SDGs real within the academic sector for the activities of the management, the leadership, the community.

The authors concluded that the Quadruple Helix Model can possibly be divided into further Triple Helix Models with a combination including, on the one hand, the appearance of the university-industry-economic connection, on the other hand, the partnership of the university-governance-community.

3.5 Science Parks, Living Labs, Start-Ups

As part of the third mission of universities, the science and innovation parks became popular worldwide, as knowledge exchange, technology transfer, like the innovation creating processes as catalysing tools of the policy. While analysing the connection between science parks and the universities with systematic literary review approach, the research group [23] concluded that the development of the literature in this topic can be divided into three major parts: before 2000 is the creation of the STPs, between 2000-2010 the geographical extension of STPs, from 2011 the thematization of the STPs (open innovation, sustainability etc.) which is further developing together with the understanding of the innovation. The researchers noted the lack of endeavour to get the new information which can shed light on the operation of the innovation process and the role of the universities in this procedure, because they found that most of the literary reviews of the STPs concentrated on the analysis of the case studies of one-to-one science parks.

When the Quadruple Helix Model is used, we can apply the approach of the Living Labs during the innovation processes in which the focus is on the end-users [24]. A research group, reviewing the literature of the investigating of the possibilities and the barriers of the Living Labs of the HEIs, reached the result in their study that the Living Labs evolved into a more individual block with a bottom-up approach to solve social challenges [25]. The model of the Living Labs (LL) requires from the multi actors and diverse stakeholders close contact and building capacity, as well as the concentration on the inter- and trans- disciplinary research methods.

While investigating the cooperation with the university and the start-ups in Germany, the authors concluded that the HEIs, to fulfil the third mission and in their support of their community, can provide financial aid to the start-ups with social aims for maintaining sustainability. Their research can motivate enterprises to cooperate with the HEIs beyond the activities of the incubation and acceleration [26].

3.6 Social Responsibility and Societal Innovation

The social responsibility (SR) appears in the third mission of HEIs which makes it possible to evaluate their legitimacy and accountability during the provision of excellent level of education and research. The authors highlighted [27] that there is a need for supporting political and organizational environment to make social responsibility become an applied mission in the practice of HEIs. They propose that not only should excellent teaching and research by the employees be acknowledged and rewarded but also the engagement for the social responsibility thus strengthening the internal legitimacy of the organisation and its societal safety for having a bigger social impact.

A research group stated in their study that the reacting social innovation for the societal problems can be built into the third mission of the universities [28]. They concluded that within the university younger lecturers launched the initiatives to tackle the external social challenges but also the historical, the societal and the organisational culture can be determined. They suggested to the political decisionmakers that they should develop organizational grants and incentives as a solution of the

acknowledgment of the implementing social innovational activities in the HEIs. Schuch also came to this conclusion in his study where he highlights the lack of systems of grants and incentives as well as the problems of the demand side and the lack of potential markets [29]. He pointed out that the social innovation supports the self-representation of the universities, as well as the spread of the social entrepreneurial spirit opens the gate to social innovations in higher education.

Discussions and Conclusions

This study made the definition clear by aiming to analyse and process the literature of the third missions of the HEIs published between 2020 and 2024. The research proved that to understand the third mission of HEIs the way is through presenting activities related to the concept while also simultaneously describing their possible impacts.

Based on the research, it can be concluded that every HEI has got their own embeddedness which influences the possibilities of the third mission activities, depending on the type of economical, civil and governmental organisations functioning within their operational area, furthermore what networking possibilities they can have as well as the how well-known they are by the local society. The higher educational institute can appear as a trigger of the multiplier effects for the economy of a town and its region through its activities, however without the institute a slow decline can be experienced instead of development [6]. The HEIs are dedicated to Lifelong Learning, along with the needs of the actors of the regional labour markets, they can also help the employees of the organisations renew their knowledge, as well as helping with the process of retraining thus contributing to the maintenance the employment.

In the model of the entrepreneurial university, the entrepreneurial spirit can appear in the activities of HEIs to strengthen the local economy with supporting new business ventures, which complements the SDGs, also it makes the spread of sustainable, entrepreneurial culture possible. Implementing the science and innovation parks with the role of the HEIs can catalyse the processes of the knowledge exchange and the transfer of knowledge, as well as the cooperations to create innovations. Applying the Living Labs approach to monitoring and reflecting the needs of the local society by involving the civilians, the HEIs have the possibility to conduct research touching on several scientific disciplines in order to strengthen their social responsibility.

When the HEIs operate in the Quadruple Helix Model, it gives them the opportunity to react to the environmental or social problems in their functional area by launching the societal innovation processes.

Providing an insight into the evolution of the examined topic through the literature and describing the possible ways of the improvement for the Hungarian HEIs was an important task of this study.

Along the further research of the third mission activities of the HEIs in the near future in Hungary, the researchers are to learn not only about the activities or developing the

assessing criteria, but also they should focus on getting current information on the motivation and attitude of the employees of the organisation, furthermore they should strive for the understanding of the inner process of the organisation, which can help fulfil the endeavours of the organisations.

#	Authors	Activities can be served as a good example
1.	Resch & Fellner & Fahrenwald & Slepcevic-Zach & Knapp & Rameder, 2020	The third mission activities of the HEIs are needed to rise to the strategic level and to be made visible for society.
2.	Unger & Marsan & Meissner & Polt & Cervantes, 2020	The Concepts of the „entrepreneurial university“ and the „citizen university“ can be mixed in a flexible way to develop creative new solutions.
3.	Corazza & Saluto, 2021	The cooperation of the HEIs operating in one region contribute to jointly creating value for a sustainable future of their district.
4.	Novela & Syarief & Fahmi & Arkeman, 2021	Applying the entrepreneurial university model to spreading the entrepreneurial spirit in the institution is the same as teaching business knowledge in the curriculum.
5.	Jirapong & Cagarman & von Arnim, 2021	Launching startups with a social mission by university financing.
6.	Monteiro & Isusi-Fagoaga & Almeida & García-Aracil, 2021	Developing the organisational system of the grants and the incentives for the community of the university to support their visions for implementing social innovations.
7.	Schmidt S., Stadermann J., 2022	Establishing the “innovational saloon” program to involve the members of civil society for tackling social challenges.
8.	Tercanli & Jongbloed, 2022	The Models of the “Living Labs” operating close to the HEIs can support the solution for the social challenges.
9.	Rentocchini & Rizzo, 2023	Summarizing the goals and activities of the third mission of the HEIs in a mission statement.

10	Godonoga & Sporn, 2023	The acknowledgement and grants of the commitment to social responsibility.
11	Astuty & Ikhsan & Aryanto, 2024	The entrepreneurial culture based on sustainability simultaneously makes the application of the SDGs and the entrepreneurial university model possible.

Table 1

Examples of best practice for supporting the third mission activities of the HEIs

Source: the table is based on the collection by the authors.

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Social Initiatives in Support of the State: A Mechanism for Enhancing Societal Resilience and Development

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Abstract: Individual states are generally expected to protect and care for their citizens by creating and enforcing laws, supporting various underprivileged groups in society, and so on. However, governments often fail to provide sufficient and timely attention to different vulnerable groups, to resolve urgent social issues quickly, and to effectively address serious challenges in such critical areas. This is where individuals, community groups, and organisations step in, supporting and complementing governmental efforts through entrepreneurial, volunteer or other kinds of initiatives – sometimes even taking over certain social functions traditionally performed by state institutions. This paper analyses these processes and highlights good examples of two young people whose ideas and actions solve specific social problems in Bulgaria. Such initiatives foster civic responsibility, promote cohesion, and contribute to sustainable development.

Keywords: social initiatives, entrepreneurship, volunteering, sustainable development

1 Introduction

States and their institutions are widely regarded as the primary actors responsible for ensuring the protection and welfare of their citizens. This includes the formulation and enforcement of legal frameworks, civil protection, the provision of public services and targeted support for disadvantaged and marginalised groups within society, among other responsibilities. Nevertheless, there is widely recognised evidence that governments often fail to respond adequately or promptly to the needs of vulnerable populations and society as a whole. In response, various social initiatives – of individuals, public groups or legal organisations – has emerged, aimed at addressing social problems and contributing to the public good, supporting and complementing the role of the state. These initiatives range from informal personal projects, through local community activities, to organised efforts by non-governmental organisations, non-profit organisations, or social enterprises established with specific goals. They may have various focuses, but what they have in common is that they are based on needs in society identified by individuals who are highly motivated and take action to

meet these needs, often attracting like-minded people, volunteers, and supporting specialists and organisations. Their activities and the positive results they achieve often have an inspiring effect and help to increase civic engagement and responsibility, thereby contributing to sustainable development. The aim of this paper is to show, through the examples of two proactive and committed young Bulgarians, that citizens' social initiatives can complement the state in performing its social functions and contribute to enhancing societal resilience and development.

2 Conceptual basis

Social initiatives are actions that benefit society and are typically driven by an individual's personal desire to help others. These actions can vary from supporting people from communities in need, participating in social activism, recycling, etc. They are based on someone's individual concerns, personal values, own motives and particular goals, seeking to address problems of society. At the same time, these actions are often carried out within a team or a social entity (group, organisation, or community) (Fernandez, 2021).

For the purposes of this paper, two forms of implementing social initiatives will be considered, which often intertwine, complement each other, and support the state in fulfilling its social commitments.

The **non-profit organisations** (NPOs) are typically dedicated to pursuing mission-oriented goals through the collective actions of citizens. As they are not formed and organised so as to generate profit, usually they do not have commercial business models and rely on donations, grants, and fundraising to support their mission. NPOs encompass a wide array of entities, including foundations, charities, educational or cultural institutions, philanthropy or advocacy groups, etc., often involving some degree of voluntary participation. Their primary objective is to address societal needs and contribute to the public good, commonly filling gaps left by the public and private sectors.

Volunteers play an important role in the implementation of social initiatives of individuals, NPOs or other kind of organisations. Social enterprises rely on volunteers who are willing to contribute to achieve the organisation's social mission (Dentchev et al., 2022). There are number of definitions of **volunteering** differing by their scope and direction, such as: "conducting work or activity without payment, for those outside of the family or household" (Nichol et al, 2023); "conscious, voluntary and unpaid activity (of a person or non-governmental organisation) aimed at achieving a social effect in the process of solving social, economic, environmental or other challenges of modern society within the limits of one's professional competences and in one's free time free from the main work" (Lenov, 2023). As already stated, this activity is often carried out within social initiatives, but can also be accomplished independently. It is

motivated by the free will and desire of the individual (Salamon & Sokolowski, 2016), rather than by the pursuit of material benefits or under external pressure. Volunteers have been found to be the first to donate not only labour, energy, time and expertise, but also funds to the causes they are involved with because they realize the importance of even the smallest donation (Toncheva-Zlatkova, 2023).

Engagement in social initiatives and volunteering has a number of personal intangible benefits for the individuals devoted to them, but it also helps the state to respond to society's demands or other contemporary challenges. That is why governments often encourage, support or at least try not to hinder such actions, as they reduce social tension caused by the state's inability to solve pressing problems. There are also a number of benefits for the society, including more accessible and quality social, health, educational and other services, increasing social capital and strengthening social inclusion.

The topic of social initiatives and volunteering is of particular importance in the Bulgarian context. In general, people in the country develop various social initiatives and entrepreneurial businesses, but are not particularly active in volunteering, although in recent years there has been significant progress in this area. There have also been repeated attempts to adopt a law on volunteering in Bulgaria over the years, incl. now, in mid-2025.

3 Methods

The research methods employed in this work include: a review of existing research findings and publications on the topic; the collection of secondary source information about the two young Bulgarians featured in the study (including websites, publications by and about them, media interviews, and podcast appearances), followed by the synthesis, chronological presentation, and analysis of this information; the conducting of two interviews with one of the subjects, Ralitsa Kolarova; and finally, the summarising of the results and drawing of conclusions.

4 Good examples and discussion

4.1 Ralitsa Kolarova and her platform “I achieve myself - Informed for success!”

In the current year, 2025, Ralitsa is a 21-year-old student living in Sofia, Bulgaria. Two years ago, during her final year at school, she developed a social project for her

Civic Education course, focused on the informational needs of children with a single parent or no parents at all. This project soon evolved into an extremely important personal cause, as she herself had once needed information about the available opportunities for receiving help and support during a difficult time in her life. While both state and private support options do exist, the information about them often remains inaccessible – hidden away somewhere and failing to reach those who need it. Ralitsa recognised this, and even while still a schoolgirl, she created her own platform to help other young people like her stay informed and navigate the bureaucracy. She firmly believes that in doing so, these young people will be encouraged to continue their education, to grow and develop, and to build a successful future for themselves.

A bit more about the project:

In every country, the responsible institutions are aware of how many children have only one living parent or no parents at all, and they develop mechanisms to help them feel more secure and valued as citizens. Bulgaria also has such mechanisms in place. Unfortunately, however, the necessary steps are often not taken to ensure that these children are informed about their rights and the opportunities available to them. That is why, following a preliminary conducted survey that confirmed a lack of sufficient awareness, Ralitsa created the platform <https://sampostigam.org/> (“I achieve myself”). The aim was to help fill this information gap by gathering in one place the opportunities for financial, material, and personal support – both from public and private sources – available to these children. The target group includes schoolchildren and university students in Bulgaria who have one living parent or no parents; those who have grown up or are growing up in institutions; or who are in the care of relatives. The website is also intended to support the single alive parents, guardians, and custodians.

The website’s motto, “*Informed for Success!*”, clearly expresses its main goal: providing easy access to information as a springboard to achievement. As an active young person with a noble cause, Ralitsa quickly gained support from NGOs and business organisations, and received help in promoting the site from schools, universities, the media, and the state itself (represented by the two directly responsible Bulgarian institutions: the Ministry of Education and Science and the Ministry of Labour and Social Policy). These institutions also supported the implementation of a second survey by sharing the website across their networks and with end beneficiaries. The *Blagotvoritel*¹ Foundation is the platform’s main financial, promotional, and communications partner, having supported both its creation and development.

Ralitsa is currently in the process of establishing NPOs (likely a foundation), which will allow her to communicate and engage with various stakeholders (primarily state authorities, volunteers, donors, funders, and other supporters) in a more transparent and authoritative manner, as well as to reach an ever-growing number of beneficiaries. The platform is continuously being enriched with information on: public and private support available to pupils and students in such disadvantaged situations; scholarship

¹ A Bulgarian word, meaning a person who is doing charity.

programmes for pupils with one parent or no parents (placed in the care of relatives); scholarship programmes for children without parents living in institutions; opportunities available to guardians and custodians of such children; news in this field; etc. The young lady is particularly active in personally promoting her initiative, taking part in radio and television programmes, podcasts, lectures for students, and other public engagements.

All of this is already bearing fruit, as evidenced by letters of appreciation from young people who have benefited from the information gathered for them. Around Ralitsa, a circle of experts has also formed – offering voluntary support in the form of mentoring, consultancy, financial assistance, technical help (including free hosting provided by bCloud.Club), and other types of aid for the initiative. However, in order for her to fully achieve her goals, there is still work to be done, especially in overcoming bureaucratic obstacles – including the site to be further promoted, as well as to start being used and enriched by state institutions, so that the information can reach more and more disadvantaged youth.

4.2 Lazar Radkov and his voluntary initiatives

Lazar is 41 years old man who, for the past eight years, has been launching volunteer initiatives that inspire and attract hundreds of thousands of like-minded people, with their most visible result being the saving of dozens of human lives.

Lazar was born in Plovdiv, the second-largest city in Bulgaria. He completed his higher education in Germany, where he initially studied engineering, but later changed direction and graduated with a degree in Nutrition Science. In addition, he passed a course to become a paramedic and volunteered with emergency medical teams in Bulgaria. He founded his own fitness and healthy eating company, but alongside running his business, he also devotes a great deal of time and effort to initiatives aimed at improving health awareness among people in Bulgaria. To support this work, he established a foundation bearing his name. His passion for sport and his knowledge of nutrition have earned the trust of his followers and made him a role model.

Despite his success in business and the positive impact of his efforts to raise awareness and encourage people to take greater responsibility for their own health (through organising mass challenges and flash mobs, contributing regular features to social and public media, writing articles and books, giving public lectures, etc.), Lazar felt a strong desire to give much more. At the same time, he believed he had the strength to achieve something far greater, that could transform the environment and improve people's lives in Bulgaria. This is how the idea for “Caps for the Future” came about, which soon after its launch absorbed all of Lazar's energy. His entrepreneurial business became a secondary occupation, which, however, financed the “Caps” initiative for quite some time. Although Lazar intends to pay more attention to this business in the future, he has now almost completely stepped away from it due to his changed focus of enthusiasm towards non-profit initiatives that help people, save lives, create

cohesive communities dedicated to doing good and enhance people's readiness to demonstrate mass solidarity. His volunteer endeavours and campaigns are numerous, among which there are some aimed at people at risk from countries close to Bulgaria. Lazar thinks that the power of civic engagement and volunteering is one of the three forces that drives society forward, alongside economic and political power.

Here we will focus on two of his large-scale volunteer initiatives:

4.2.1 “Caps for the Future”

The idea of collecting and recycling plastic bottle caps did not originally come from Lazar Radkov, of course. Such initiatives exist in a number of European countries, including Bulgaria. A few years before “Caps for the Future” was launched, there had been two similar undertakings in Bulgaria aimed at helping people in need. However, by 2017, when the group of training with Lazar people decided to start collecting caps (because they use a lot of bottles during training), those earlier initiatives were no longer active.

Since then, “Caps for the Future” (<https://www.facebook.com/kapachkizabudeshte>) has become one of Bulgaria's most loved social initiatives, supported by both the business and the citizens from all parts of the country. It has two main goals: 1) to collect plastic caps, which are handed over for recycling, taking care of the environment; 2) with the money received, the huge chronic deficits in the healthcare system to be reduced. The small change from the caps is not enough to help all hospitals, so they have targeted it at the hope of the nation – babies, buying and delivering incubators and other necessary equipment for neonatology wards across the country, mainly in smaller towns.

The results of the campaigns are becoming exponentially more significant each year. In addition to the vast number of people collecting and handing in tonnes of caps for recycling (between 230 and 250 tonnes annually), thousands of individuals are voluntarily involved in organising the process. However, the funds raised from recycling caps account for less than half of the total amount received by the Lazar Radkov's foundation, which manages “Caps for the Future” – the greater portion of the funding comes from corporate and private donors, as well as from the sale of merchandise. Thanks to the initiative, five specialised children's ambulances and other four specialised for other purposes have been purchased and donated to Bulgarian hospitals, along with over 25 incubators and various medical devices and specialised equipment, worth more than half a million euros. Renovations of hospital wards have also been carried out, along with other related activities. None of the people involved in the initiative receives a salary or any funds from the foundation. Lazar insists on this in order to ensure full transparency in the use of funds and to prevent any grounds for speculation or mistrust. He supports himself by leading physical training sessions.

“Caps for the Future” is an excellent example of how little personal efforts can create a huge change and a “snowball” effect of kindness in the society.

4.2.2 “Rescue club for the Future”

As a next step, the initiative “Rescue club for the Future” (<https://spasitelen.club/>) was launched in autumn 2023. It develops a network of clubs, which, under the Bulgarian Disaster Protection Act, function as voluntary formations for the prevention or management of disasters, fires, and emergencies, as well as for dealing with their aftermath. The clubs operate under the umbrella of Lazar Radkov’s foundation and are funded through participants’ own contributions, the foundation itself, or private donors. The clubs support the General Directorate for Fire Safety and Civil Protection of the Ministry of the Interior. There are already ten such clubs in eight cities across Bulgaria, with over 150 professionally trained, experienced, and well-equipped volunteers providing assistance in disaster situations. “Rescue club for the Future” is already recognised and actively involved in tackling forest fires, supporting drainage operations, and participating in search and rescue missions. One of the ideas for expanding the initiative is the formation of youth rescue clubs.

This volunteer formation is developing not only as a rescue organisation but also as a symbol of civic engagement and solidarity in Bulgaria.

Conclusions and implications for the future

A developed society should be democratic, civically active, and socially responsible.

Ralitsa wants to contribute to the creation of such a society in Bulgaria – one in which the state is able to protect rights and guide young people from disadvantaged social backgrounds towards a better future. With the expected stronger partnership and collaboration between the state and the legal entity that Ralitsa will establish, “I achieve myself” will gain sustainability and serve as an example of a citizen-created mechanism that benefits both the state and at-risk target groups.

Lazar has a vision for the development of Bulgaria through volunteering and how this can be achieved – in areas where he can personally contribute. He believes that with a little more effort, significant results can be achieved in the development of society through caring for oneself and for others, including the vulnerable and those in disadvantaged or at-risk situations. A step towards realising this vision was the establishment of local “Clubs for the Future” (that are without rescue activities) in 2022 across 30 Bulgarian towns, developed by local residents. These clubs not only support the “Caps for the Future” campaign locally but also have a broader focus on volunteering through causes aimed at improving the local environment. Another volunteer initiative involving medically trained individuals is the delivery of first aid training in schools, which has so far reached over 8,000 pupils.

The two good examples presented within this paper show that we should not rely on the state for everything or complain that it is to blame, but rather take matters into our own hands and strive every day to improve our own lives and those of others.

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The role of security-effects of cognitive based and emotional trust

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Abstract: The basis of all communication is security and trust. This study aims to be a secondary research summarizing scientific articles and research investigating effective organizational communication. Effective organizational communication is important, among other relevant factors, in terms of the quality of life of the employees in the organization, in terms of the organization's partner relationships, and in the issue of adapting to continuous changes. Effective organizational communication enables people to interpret reality together, summarizing individual interpretations.

Keywords: organizational trust, innovation, security, communication

1 Introduction

Is trust a good or a bad phenomenon? Does it always depend on the given situation whether trust is born? Or are there general, always valid criteria and foundations for trust?

The phenomenon of exactly how we trust another person has been the focus of research for a long time. Examining both individual and organizational trust, many authors have concluded that quite a lot of components of trust are known and that trust cannot be measured on a single level.

Grammatical and linguistic interpretations of trust serve as an excellent basis for adequately establishing the complexity of the topic. According to Kovács (2021), trust as an expression is a comprehensive phenomenon that can be interpreted as a speech act. The complexity of the question is caused by the second part of the author's assumption, according to which the speech act has a trust dimension. The proposition can be formulated that communication presupposes trust, and thanks to trust, communication becomes more efficient and complete. Trust extends from the most personal level, from self-confidence, to the most comprehensive network of relationships, from social trust.

Every day we live in a state of fluctuation between trust/distrust. Deep within trust/distrust, in relation to relationships between people, an insoluble aporia can be grasped: there is trust, but not yet; there is no trust, but nevertheless there is. No community can function without the presence of trust, but at the same time, no community can assume the full realization of trust. In other words, there is always a given level of trust or distrust, in which trust is constantly exposed to distrust and vice versa. The full fulfillment of trust can be considered a borderline situation or an extraordinary state, which manifests itself in exceptional moments of peace (finding love, security, harmony with ourselves and the world). Similarly, the radical form of distrust is fulfilled in war (we fear losing our loved ones or our lives, we fear becoming homeless). (Kovács, 2021)

2 Method: review of scientific literature on the topic of organizational trust

There is a general consensus among contemporary social scientists that social trust is important. (Delhey&Newton, 2003)

In the “new normal” after the Covid-19 pandemic, working methods, communication channels, and thus the everyday lives of organizations and leaders have changed permanently, and new global challenges are emerging. Szathmári&Kiss (2024) sought to answer the question of how individual leadership roles develop in this situation from the perspective of leaders and their subordinates, and how these are related to organizational trust and leadership styles.

Organizational theory holds that communication is the lifeblood of all organizational cultures, and even organizations. (Vári, 2016)

According to Fukuyama (1995), due to the social embeddedness of the economy, relationships are regulated not only by the cost-benefit principle, contracts, and sanctions that assume self-interest, which the author calls the “tax of distrust” due to their cost implications, but also by mutual trust between members of society.

Mutual trust as social capital influences the willingness to associate and can serve as a basis for the effective exploitation of economic opportunities of companies, as well as the well-being of the organization's members (Sass, 2011).

The family is the oldest and smallest unit of human coexistence, which has been the basic unit of society and economy for thousands of years, and therefore the family business is one of the oldest forms of business. Families all over the world create naturally occurring communities that are built on trust relationships (Fukuyama, 1995). Businesses with a family dimension therefore tend to use trust as a management mechanism in their operations. The economic importance of family businesses today

is clearly demonstrated by the fact that 90% of companies in Germany are managed by families, which account for more than half of GDP. (Vajda, 2020)

Studies on trust, which concern different levels of phenomena, have to date nuanced the ideas regarding the unilaterally positive effect of trust. The negative effects of excessive trust have also been shown. Consequently, the question may arise as to what is the optimal level of trust and how different levels of trust affect organizational functioning. In a trust relationship, in addition to the cognitive evaluation of experiences, emotional factors also play a role in information processing. The uncertainty due to the risk of trusting causes direct emotional reactions. The background emotions experienced during the decision (favorable/unfavorable) and the emotions resulting from the evaluation of the consequences have an effect. (Sass, 2005)

The study of organizational trust is justified by research results that indicate that the beneficial effects of trust can be identified for both individuals and organizations. At the individual level, this includes the role of trust in reducing workplace stress and increasing performance. At the organizational level, trust contributes to increased organizational efficiency and performance by facilitating cooperation, obedience, and information sharing.

Both emotional and cognitive processes play a role in these favorable consequences. The beneficial effect of trust can be realized in several ways, and research highlights the influence on the feeling of uncertainty and the development of organizational relationships. Organizational trust, as a means of organizational coordination, makes interactions predictable, reduces perceived uncertainty in the workplace, while trust in colleagues and managers facilitates social exchanges and creates greater commitment to the workplace. (Sass-Bodnár, 2018)

3 Results

The literature on social trust contains different theories of the origins and determinants of social trust. It also contains many conflicting empirical findings, even within the same country, and especially in cross-national research. In Delhey & Newton's (2003) article they identify six main theories of trust, ranging from bottom-up, individual ones to top-down, societal ones. These theories run in parallel with different interpretations of the concept of trust itself. Some see it as a social-psychological property of individuals. People are 'trusters' or 'distrusters' according to how they were brought up, or according to their experience of later life. Others argue that trust is a social property and a contextual variable. Individuals don't 'have' it as a personal attribute, so much as evaluate the society in which they live as generally trustworthy or untrustworthy. The more people believe that others are to be trusted, the more they will act in a trustworthy manner themselves, and the more they will reinforce the virtual

circle of trust. In this sense, trust is a contextual or emergent property of social systems, which means that it is a social good that is fortified by constant use.

Delhey&Newton's (2004) finding results, that cross-national comparative analysis of generalised social trust in 60 countries shows that it is associated with, and is an integral part of, a tight syndrome of cultural, social, economic, and political variables. High trust countries are characterized by ethnic homogeneity, Protestant religious traditions, good government, wealth (GDP per capita), and income equality. This particular combination is most marked in the high trust Nordic countries but when this group of outliers is removed from the analysis, the same general pattern is found in the remaining 55 countries, albeit in a weaker form. There are indications that rural societies tend to have comparatively low levels of generalized trust but no evidence that large-scale urban society tends to undermine trust.

The cause and effect relations between trust and its correlates are impossible to specify but the results suggest that the ethnic homogeneity and Protestant traditions have a direct impact on trust, and an indirect one through their consequences for good government, wealth and income equality. The importance of ethnic homogeneity for generalised trust also suggests that the difference between particularised and generalised trust may be one of degree rather than kind. (Delhey&Newton, 2004)

Generalized trust has become a paramount topic throughout the social sciences, in its own right and as the key civic component of social capital. To date, cross-national research relies on the standard question: "Generally speaking, would you say that most people can be trusted or that you need to be very careful in dealing with people?" Yet the radius problem—that is, how wide a circle of others respondents imagine as "most people"—makes comparisons between individuals and countries problematic. Until now, much about the radius problem has been speculation, but data for 51 countries from the latest World Values Survey make it possible to estimate how wide the trust radius actually is. We do this by relating responses to the standard trust question to a new battery of items that measures in-group and out-group trust. In 41 out of 51 countries, "most people" in the standard question predominantly connotes out-groups. To this extent, it is a valid measure of general trust in others. Nevertheless, the radius of "most people" varies considerably across countries; it is substantially narrower in Confucian countries and wider in wealthy countries. Some country rankings on trust thus change dramatically when the standard question is replaced by a radius-adjusted trust score. In cross-country regressions, the radius of trust matters for civic attitudes and behaviors because the assumed civic nature of trust depends on a wide radius. (Delhey et al., 2011)

Theories	Variables
Individual Personality theory Success and well-being theory	Optimism, life control Income, social status, life satisfaction, job satisfaction, happiness, anxiety Membership of voluntary associations Networks of friends
Social Voluntary organisation theory Social network theory Community theory Societal theory	City size, satisfaction with the community, community safety Social conflicts, satisfaction with democratic institutions, political freedom, public safety

Table 1

Six theories of trust and related variables

Source: Delhey, J., & Newton, K. (2003). Who trusts?: The origins of social trust in seven societies. European societies

Bencsik&Juhász (2018) pointed out that at the micro level, trust is related to the following factors: employee satisfaction, performance, behavior, teamwork, leadership effectiveness, human resource management perceptions, successful negotiations, communication, commitment, ethical behavior, corporate partnerships, etc. Based on these, it is considered a fundamental influencing factor in the internal functioning of organizations. At the macro level, trust is the driving force behind organizational change and survival, corporate cooperation, strategic alliances and mergers or acquisitions.

The benefits of organizational trust	cost reducer	driving force for organizational change
	conflict reducer	driving force
	the organization's performance increases	ethical behavior
	competitive advantage	corporate collaborations
	employee dissatisfaction	teamwork
	successful negotiations	commitment

Table 2

Organizational trust objects

Source: SASS, J. (2005). Trust patterns and trust decisions in the organization. Own editing based on the Doctoral School of Psychology, University of Pécs

Based on the questions posed by Sass (2005), it conducted an investigation of two phenomena. One is to explore and measure the components of organizational trust - according to its object and basis -, to examine the relationship between these components, and to identify and typify the trust patterns of the organizations examined, which differ according to their components. The other goal is to examine individual decisions dependent on the level of organizational trust or lack of trust in organizational trust dilemmas. The investigation supports the hypothesis that in a given social system, organizational trust, according to its object, applies to three areas: organizational operation, the immediate manager, and the group of colleagues. Organizational trust is a complex phenomenon that is composed of components that can be separated according to the trust object (predictability, reliability, benevolence), which can be measured separately. Sass (2005) found that cognitive and emotional trust bases appear in relation to all three trust objects. Since trust is formed on a different experiential basis in relation to trust objects, and this trust experience in the organization is influenced by institutional, task and personal and intergroup relationship experience, cognitive and emotional trust bases can be distinguished. Regarding the relationship between the individual trust objects, the correlations support our assumption that employee, management and system trust jointly determine trust in the organization. (Sass, 2005)

Swift&Hwang's (2013) paper examines the influence of one conceptualization of trust, one that has two sub-constructs – affective (emotional) trust and cognitive (rational)

trust – on knowledge sharing among 157 marketing and sales executives. Their results indicate that affective trust is more important than cognitive trust in sharing interpersonal knowledge, but cognitive trust is more important in creating an organizational learning environment. (Swift&Hwang, 2013)

	<i>Most people can be trusted (%)</i>	<i>Valid n</i>
South Korea	60	1,000
Switzerland	43	984
East Germany	35	473
West Germany	32	1,888
Spain	28	2,381
Hungary	18	1,422
Slovenia	14	972

Table 3

Trust in seven countries

Source: Delhey, J., & Newton, K. (2003). Who trusts?: The origins of social trust in seven societies. European societies

Conclusions

Many studies in the field of risk perception and acceptance of hazards include trust as an explanatory variable. Despite this, the importance of trust has often been questioned. The relevant issue is not only whether trust is crucial but also the form of trust that people rely on in a given situation. In this review, I discuss various trust models and the relationship between trust and affect heuristics. I conclude that the importance of trust varies by hazard and respondent group. Most of the studies use surveys that provide limited information about causality. Future research should focus more on experiments that test whether trust is a consequence of people's attitudes or influences their attitudes toward a technology. Furthermore, there is a need for a better understanding about the factors that determine which heuristics people rely on when evaluating hazards. (Siegrist, 2021)

Trust is an essential ingredient in our daily activities. The fact that these activities are increasingly carried out using the large number of available services on the Internet makes it necessary to understand how users perceive trust in the online environment. A wide body of literature concerning trust perception and ways to model it already exists. A trust perception model generally lists a set of factors influencing a person trusting another person, a computer, or a website. Different models define different set of factors, but a single unifying model, applicable to multiple scenarios in different settings, is still missing. Moreover, there are no conclusions on the importance each factor has on trust perception. In this paper, we review the existing literature and

provide a general trust perception model, which is able to measure the trustworthiness of a website. Such a model takes into account a comprehensive set of trust factors, ranking them based on their importance, and can be easily adapted to different application domains. A user study has been used to determine the importance, or weight, of each factor. The results of the study show evidence that such weight differs from one application domain (e.g. e-banking or e-health) to another. We also demonstrate that the weight of certain factors is related to the users knowledge in the IT Security field. (Costante et al., 2011)

In the “new normal” after the Covid-19 pandemic, working methods, communication channels, and thus the everyday lives of organizations and leaders have changed permanently, and new global challenges are emerging. Szathmári&Kiss (2024) sought to answer the question of how individual leadership roles develop in this situation from the perspective of leaders and their subordinates, and how these are related to organizational trust and leadership styles.

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Understanding the Second-hand Clothing Market and its impact on Ghana

(Case study on the Kantamanto Market)

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Abstract: The global second-hand clothing (SHC) market has experienced rapid growth, fuelled by fast fashion, evolving consumer preferences toward sustainable fashion and economic affordability. Key drivers behind this growth include heightened environmental awareness, economic pressures, and the adoption of a "circular economy" mindset, where reusing goods is increasingly prioritised by many consumer groups over new single-use consumption. The SHC market creates avenues for increased access to affordable clothing for low-income communities, supports informal job creation in buying, selling, repairing, and altering garments, and promotes sustainable practices aligned with circular economy principles.

Research from the Swiss Academy for Development in 1997 indicated that over 95% of Ghanaians consume or patronise second-hand clothing, demonstrating its pivotal role in the apparel market. Similarly, a study by Oteng-Ababio et al. identified the Kantamanto Market in Accra as a central hub for the second-hand clothing industry in Ghana and neighbouring countries (Oteng Ababio, 2015).

This local study aims to develop a more robust understanding of how resale, repair, and preparation for reuse operate in Ghana and map the adverse impacts associated with the importation of second-hand clothing. The study also evaluates awareness of policy and regulation within the SHC industry.

This study was conducted through Project Rewear, initiated by Fashion For Good (FFG) and Circle Economy (CE) in partnership with The Revival Earth and Artidiction. Project Rewear focuses on the current and desired future state for resale end destinations like Kantamanto, per product archetype (Denim Jeans, Outerwear, T-shirts, Activewear, Sweatshirts or Jumpers) by looking at rewearable and low-value rewearables, and identifying the resale and repair potential of garments in four select European regions: Lithuania (Nordic/Baltic), the Netherlands (Western), Poland (Central-Eastern), and Spain (Southern Europe).

Keywords: Kantamanto, rewear, repair, resale, garment, bale, textile waste

1 Literature Review

A resale report by ThredUP (2023) revealed that the global second-hand apparel market could reach an estimated \$350 billion by 2027. As of 2023, the global second-hand apparel market saw a growth rate of 28% at a value of \$211 billion, although it was estimated to reach a rate of 24% at a value of \$141B in 2022 (ThredUP Resale Report, 2022). Key drivers behind this growth include heightened environmental awareness, economic pressures, and the adoption of a "circular economy" mindset, where reusing goods is increasingly prioritised by many consumer groups over new single-use consumption.

For many Ghanaians, second-hand clothing provides high-quality and unique items at a fraction of the price of new garments. The industry supports local enterprises such as tailors and repair shops, which benefit from the demand for garment alterations and repairs, fostering a culture of repair rather than disposal.

A study by Oteng Ababio et al. identified the Kantamanto Market in Accra as a central hub for the second-hand clothing industry in Ghana (Oteng Ababio, 2015). Often referred to as the "bend-down boutique" by locals, Kantamanto Market offers an expansive array of used apparel, attracting consumers from diverse backgrounds.

In Kantamanto, approximately 100 containers are received weekly, with about 15 million used clothing circulated weekly. "Ghana has a population of 31 million people, so it is unlikely that all the 30 million garments that arrive every fortnight will be sold. The supply exceeds the demand (Kekeli Ahiabile et al. 2021). The gap between demand and supply creates waste.

Recently, second-hand clothing traders have complained about the declining quality of imported bales, which is believed to be a key contributor to the textile waste crisis in Ghana. The city of Accra, which receives higher volumes of low-quality bales, has become a dumping ground for vast quantities of discarded clothing from the Global North. The second-hand clothing sent in from overseas includes a lot of clothing that may not be useful, hence ending up in landfills and the oceans as waste.

In addition to the above concerns, the SHC trader has a negative impact on the local textile industry in Ghana. By the year 2000, Ghana's textile industry, once employing over 25,000 workers in the 1980s, had shrunk to fewer than 3,000 workers, with major factories like Akosombo Textiles Limited (ATL) and Juapong Textiles scaling down or closing entirely (Quartey, P. 2006).

2 Methodology

This study focused on Ghana's Kantamanto Market in Accra, a primary hub for second-hand goods. Kantamanto Market is the largest second-hand clothing market in Ghana, serving as a central hub for importing, selling, and distributing second-hand clothing.

The data collection began on October 18 and ended on December 3, 2024. This period was a peak season for traders as customers rushed in to shop for the end-of-year festivities. The study provides a comprehensive investigation into the complex dynamics of this market, including a detailed analysis of stakeholders, infrastructure, key activities, product quality, repair practices, pricing structures, textile waste disposal methods, and the flow and management of the second-hand clothing trade.

Table 1 outlines the various research methods used in this study, detailing the target stakeholders, sample sizes, and the specific purpose of each approach.

Method	Target / Stakeholders	Size	Purpose
Desktop Research	Local and international reports in connection with the study location and type	N/A	Analysis of secondary data (Existing data/reports).
Survey	Wholesale/retail traders selling product archetype.	107	Gather general trade data... Infrastructure and activities, SHC Market, Repair culture, quality, pricing and others
Observation	Selected traders according to the product archetype	10 stores	Repair and sorting processes with a focus on product archetype
Sorting	Collection of textile waste for sorting. 1.33 tonnes of waste clothes	2,473 garments	Independent sorting of textile waste for material composition and condition.
Interview	Accra Metropolitan Assembly, Environmental Protection Agency, Kantamanto Second-hand	8	Focus on regulations and policies, interventions, infrastructural support, and others

	Clothing Association, Repair Traders, Upcycling organisation and Importers.		
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Table 1
Defining the data per the Methodology

2.1 Data Collection Methods

2.1.1 Surveys and Trader Engagement

Six trained data collectors engaged directly with traders and retailers to gather detailed information such as:

- Duration of involvement in the second-hand clothing business.
- Profitability and economic viability of their trade.
- Country of origin of their stock and procurement processes.
- Cost of goods and pricing structures.
- Policy awareness

One hundred and seven (107) traders were engaged, and their responses were submitted via a Google form. Traders were selected and engaged according to the product archetypes.

2.1.2 Observations Method

Observation activity focused on selected traders within the market. Researchers examined the handling and selling specific product archetypes, including denim, outerwear, t-shirts, and sweatshirts. Data was collected based on product quality, repair practices, waste management culture, price and consumer interactions with these items.



Figure 1.
Sorting activity with the research team

2.1.3 Waste Collection and Sorting

Traders were asked to bring in their textile waste, for which they were compensated. 1.33 tonnes of garments were collected. The collected waste was sorted and classified according to the market's grading.

2.1.4 Interviews and Stakeholder Engagement

To gain deeper insights into trade challenges and opportunities, interviews were conducted with stakeholders, such as long-term market participants, local authorities, importers, etc.

A purposive sampling approach was used to select participants and archetypes, ensuring diverse representation across trader types and product categories. The study used a qualitative and quantitative approach better to understand the actual state of the Kantamanto SHC market. It attempted to consider all the stakeholders in the ecosystem

and other external players relevant in finding a sustainable solution to the textile waste crisis.

3 Findings

3.1 The Kantamanto Ecosystem

Kantamanto has developed a unique support system that contributes to the resilient nature of the business. Kantamanto market is spread across 20,000 acres of land for over 30,000 traders (Nelson C.J. Okayafrica, 2024). Kantamanto is home to over five thousand (5000) used clothing sellers, according to Mr Michael Oppong, the chairman of the Kantamanto Used Clothing Sellers Association (KUCSA). Figure 2 illustrates the current players within the market.

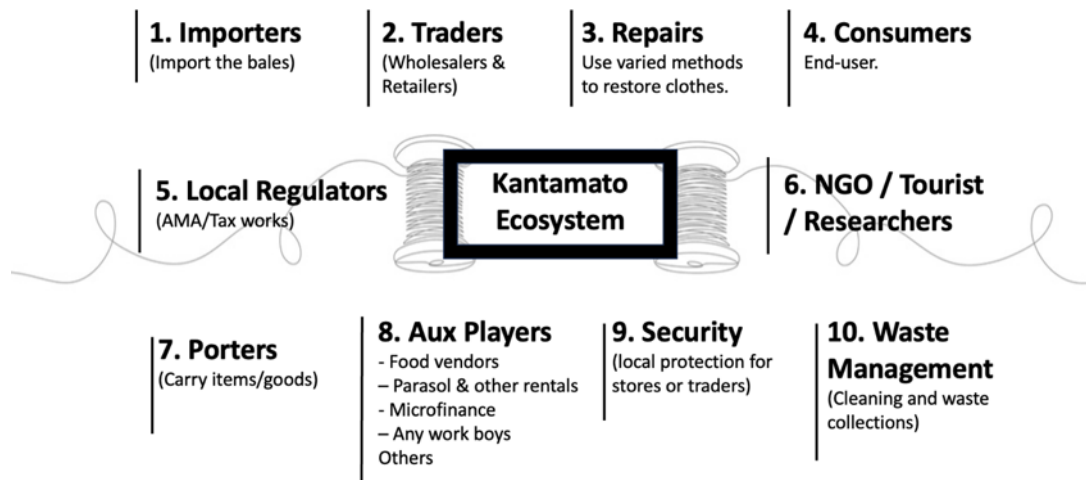


Figure 2.
Kantamanto Ecosystem

1. **Importers** facilitate the entry of second-hand clothing into the Kantamanto market. They procure large bales from global suppliers. According to the study, they are sometimes involved in sorting the bales from the sending country and sometimes re-sorting them locally.

2. **Traders (Wholesalers/ Retailers)** purchase bales from importers and sell them to market traders or directly to consumers. Some wholesalers also sell in other markets across Ghana.
3. **Repair Specialists:** These were tailors, cobblers, and other players who used special techniques to restore or upcycle second-hand items.
4. **Consumers:** This includes individuals seeking affordable clothing and those purchasing for resale.
5. **NGO/Tourist/Researchers:** These were individuals, stakeholders, and local and international organisations with diverse interests in Kantamanto and beyond. Since the recent media spotlight on Kantamanto's trade in second-hand clothing and textile waste, the market has received several visits from local and international players seeking firsthand knowledge of the waste crisis and what they could do with their findings.
6. **Auxiliary Players:** These are very important players in the market's daily operations. They include food vendors, "Kayaye" (female head porters) who carry goods for traders and consumers, parasol and other essentials rental agents, microfinance agents, work and others.
7. **Security:** Kantamanto used clothes stores to have ten lanes with the gates at both ends. There are specific times the gates are opened for trading in the morning and closed in the evening. There are no official security players who are knowledgeable about traders and how they keep their stocks in their sheds/stores. They also play diverse roles based on the time of day.
8. **Waste Management:** Kantamanto lacks a robust waste management structure. Independent waste collectors go around to collect waste at a fee. The waste is not segregated according to the materials—textiles mixed with rubber and organic waste, etc. Organisations like the Or Foundation and The Revival Earth periodically call for textile waste. However, the volume of the textile waste collected by these organisations is a fraction of the total textile waste generated daily.

On January 2, 2025, the entire Kantamanto market was burned to the ground. This devastating occurrence affected our research and caused a huge setback in improving the infrastructure gap and the working conditions of the traders. Individuals, organisations, the government, and friends (at home and abroad) have supported the market's rebuilding.

The study team made the following observations:

There was no unified approach to rebuilding a sustainable market. Over 10,000 traders were eager to revive their shops and livelihoods. Some groups have received funding from philanthropists and the government, executing their plans independently instead of adhering to a collective relief plan for the entire ecosystem. The lack of a cohesive

relief plan has raised concerns that marginalised groups, including elderly traders aged 65 and over, head-porters, and traders with disabilities, have been overlooked in the various relief opportunities.

3.2 What is textile waste?

After various surveys, interactions and observations, waste can be described as any material that is no longer of value to the user. That is to say that a trader may discard an item as waste, but another user may have a use for it and consider it valuable. Hence, the definition of waste depends on whose possession it is in. Our waste collection and sorting data revealed that not all the items the traders had gathered as waste were waste to others. In fact, we had scenarios where traders went around the market to collect items others had discarded. Yet, after our sorting exercise, we found that a generous percentage still had value (Grades A and B) and other things that could be repurposed. This confirms that there are diverse options on what is qualified as textile waste, even from the sending country. However, the study classifies an item as waste (textile waste) when it is not sellable and profitable.

3.3 What is a quality garment?

The opinions on quality garments vary within the Kantamanto market, but the factors determining quality remain similar. These include the texture of the material/fabric, condition of the item (if there are damages, it looks new, can be repaired/upcycled, etc.), if it fits the climate of the receiver, current fashion trends, market demands, origin of the product, size, and brand. If the factors are favourable for the trader and he or she makes a profit, the garments/bales are of good quality. The study developed the grading deck based on interactions with traders (wholesalers and Retailers) and observations during the sorting exercise per the product archetype (Table 2).

Grade A	Grade B	Grade C	Grade D
Items that are saleable and do not have any damages. These items are generally new/never used or almost as good as new.	Items are also saleable and in excellent condition. Clothes in this category are typically smaller (baby clothing, XS, etc.) or larger (X, XL, XXL, etc.).	These are items that are neither new nor clean. They have damages but can be sold. To make them saleable, they may require repairs or are sold at a reduced price.	These items ultimately become waste. They hold no value, cannot be worn, and are entirely useless.

Table 2
Defining quality per grade for SHC

3.4 Reuse and Repair Methods.

The study highlights the commonly used methods for repairing garments in Kantamanto: screen printing, dying, patching, ironing, sewing, deep washing, neatening, and stitching. According to the study, long-operating craftsmen specialise in reviving clothes regardless of their condition in the market. They use old traditional methods (tie and dye, stitching, ironing) with little interest in investing in new techniques. Sometimes, clothes are relabelled to make them trendy.

From observation and a keen look at the Kantamanto ecosystem, repurposing methods like upcycling are the least used. Most of the repairers are not familiar with modern techniques in the industry. During an interview, Stephen Ackah, a repairer and upcycler in the market, disclosed that he lacks the funding to purchase a cutter, which would boost his efficiency and productivity. Hence, he has to use scissors, which have many shortcomings. (personal communication, November 2024)

Reuse and repair practices at the Kantamanto Market exemplify a circular economy approach in action. They sustain livelihoods, minimise textile waste, and promote creativity. However, addressing challenges like waste disposal and inadequate infrastructure is crucial for enhancing these practices' long-term sustainability. These challenges can be discussed further by expanding the operations and space for repairers/upcyclers in the market, which will significantly increase the volume of upcycled textile waste daily. Policymakers and stakeholders could further support these efforts by empowering third-party organisations/NGOs like The Revival Earth and OR Foundation. They can also provide training programs, financial support for new technology/equipment, financial incentives for repair services, and import regulations to reduce the influx of unusable clothing.

3.5 What are the Price Factors, and What Influences Them?

During the research, the team recorded countless reactions from traders who mentioned that the trade was not as profitable due to the increasing percentage of textile waste. The team further conducted an observation study that focused on the factors that influence the prices of the research archetype. It is important to note that the traders were selected based on the archetype, not their clothes' quality.

There were instances when a coat with no damage was priced at GHS100.00, and similar coats with damage were priced at GHS10.00. This example clearly illustrates that damaged clothes are at a disadvantage to sellers. Ghanaian shopping culture in public markets like Kantamanto offers customers bargaining opportunities. This means there is no fixed price, and the customer and the trader have the free room to negotiate. Traders are always at a disadvantage when their clothes are damaged, are not in trend, etc.

The study also reveals other factors influencing importers' prices: the exchange rate, Freight cost, and import tax duty. Ghana has significantly increased import tax duties on second-hand clothing over the years.

The Ghanaian currency has been consistently depreciating, so if a bale costs EUR 450.00 at GHS 5,922.00 on January 1st, 2024, the same bale will cost GHS 6,871.50 on November 1st, 2024.. Post-COVID-19 has brought many economic difficulties, and the government of Ghana has introduced various forms of taxes (COVID-19 levy, E-levy, etc.) to increase its internal revenue, pay off loans, and run the country simultaneously. According to the Ghana Statistics Service, inflation for clothing and footwear rose to 41.9% in December 2022, and reduced to 24.5% in March 2024. In 2021, there was a massive increase due to these elements: Cumulative import taxes, including VAT (15%), NHIL (2.5%), GETFund levy (2.5%), and the ECOWAS levy (0.5%), brought the total tax burden on second-hand clothing to approximately 40% of the declared value. (Ghana Revenue Authority, 2021)

Importers are very aware of this unpredictable financial cycle. To stay profitable, they pass on every increase to their clients. Importers seem aligned with the sorting categorisation from the sending countries, as they are sometimes included in the processes. The interview with David Adams (Importer) was very insightful, as he plays a dual role as an importer and is also involved in the operations of seven SHC stores on behalf of his family in Kantamanto. He admits the importation process needs regulations to reduce the increasing percentage of waste. Figure 8 shows that 52.9% of 104 valid responses indicate the quality of the bales has declined.

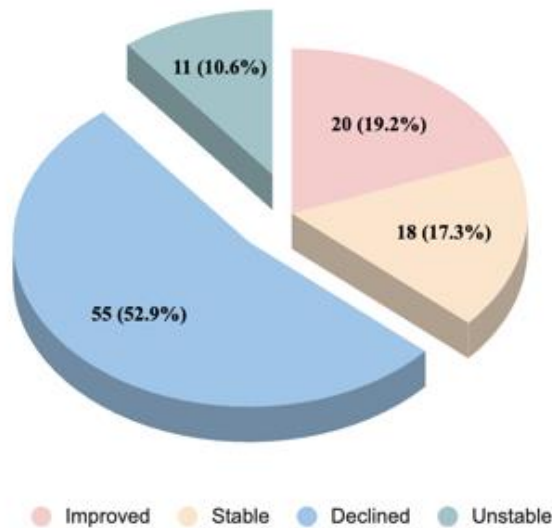


Figure 3.
Response on the quality status of the bales

Per the input from Michael Oppong (Chairman of Kantamanto Used Cloth Sellers Association), “Traders are compelled to accept the cost of bale set by the importer with no opportunity to confirm if the quality of the garments meets the trader’s expectation. Some importers who do re-sorting usually offer free consultations to their clients. Other than that, traders buy the bales on the importer’s condition and hope to profit from them. Furthermore, it is essential to highlight that price increases since the COVID-19 pandemic have not correlated with the quality of goods. The major contributors are rampant tax adjustments and currency exchange rate volatility in Ghana.

3.6 Textile waste analysis concerning materials, damages and brands.

As part of the study’s objective to collect insight on damages per project archetype, it was agreed to execute a sorting exercise for grade C and D garments. The research team called for garments in Kantamanto, and traders delivered 1,332.1kg, containing 2,474 garments. The grade C and D garments were stored and sorted within two weeks. Figure 12 shows the top ten categories of brands received during sorting. Eight hundred

forty-one (841) brands were recorded, and 24.7% of the garments were without labels. The research recorded H&M as the highest brand in the sorting exercise.

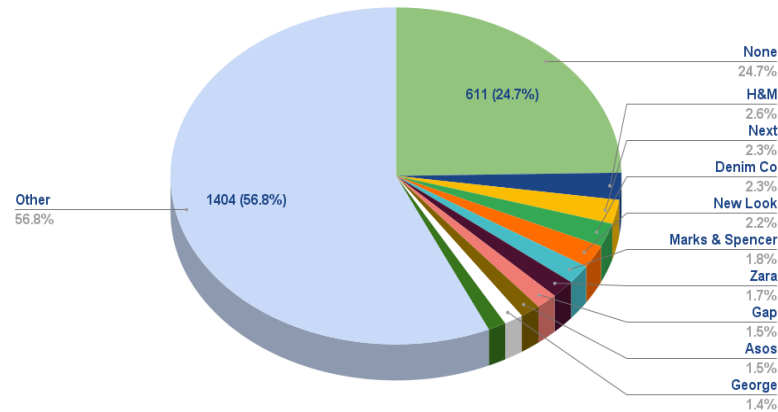


Figure 4.
Brands Collation per top 10 categories

Most garments received were C and D grades, which reflect the grades communicated during the call-out. This insight confirms that traders may be aligned with the research grading system.

The sorting activities revealed the following material types.

- **Natural Fibres:** Cotton and wool dominate, especially in categories like T-shirts, denim, and outerwear. These materials are biodegradable but require careful handling to avoid environmental impact.
- **Synthetic Fibres:** Polyester and nylon items found in activewear and outerwear contribute significantly to non-biodegradable waste.
- **Blended Fabrics:** Items combining natural and synthetic fibres present challenges in recycling due to mixed composition.

The study recorded 2140 damaged garments, 86.5% of the total (2474) received. Common Issues include frayed fabric, faded clothes, loose fabric, loose neck, etc. Repair Feasibility: Minor issues like tears and fading are often repaired, while severe damage may render items suitable only for upcycling or disposal.

As mentioned in the methodology, the damages were recorded for only the grade C and D garments. This analysis is meant to enlighten traders, importers, and textile industry players on how these damage types influence the grading quality and prices of garments locally. This information also guides sending agents in the Global North, who hope to find a collective grading matrix.

It is crucial to emphasise that the research market lacked sufficient storage facilities. The team had to carry out sorting activities in an open shed under the blazing sun, which is common in a bustling market like Kantamanto. The area does not have a storage management system, which hinders traders from tracking their items.

3.7 Waste Management Culture in Kantamanto

Over seven thousand people go about their daily routines in the Kantamanto market, which generates various forms of waste, ranging from food and organic waste to textiles and paper. Unlike in other advanced public spaces in Ghana, the market struggles to collect and segregate waste. Instead, all forms of waste are collected as one.

The Accra Metropolitan Assembly collects sanitation levies daily, which are believed to address waste and hygiene issues in the market. Sadly, this act has not significantly impacted the fight against waste in the market. Yayra Agbofah of the Revival Earth mentioned that formal and independent waste collectors help manage waste, but they are not well coordinated. The market lacks a waste management strategy. Evidently, the volume of textile waste is significantly more prominent than other forms of waste and poses a significant challenge due to inadequate infrastructure and a poor waste management culture.

As captured in the research interviews, “The Kantamanto Joint Traders’ Association, in collaboration with the OR foundation, helps collect textile waste periodically. Organisations like The Revival Earth also contribute by taking some of the waste for recycling. Yayra Agbofah emphasised that the volume of textile waste upcycled is insignificant compared to the daily volume of textile waste. This is also because Revival Earth is currently the only upcycle entity producing upcycled products and educating and collaborating with traders within Kantamanto.

Disposal Methods

- Organised Dump Sites are facilities dedicated to receiving and treating waste. According to Engineer Nii (AMA), there are very few waste management sites, and the existing sites dedicated to textile waste are not well-equipped and well-funded enough to handle the waste properly.
- Improper Dumping: These are independent waste collectors and individuals who find other convenient ways to dispose of waste. Mixed waste is disposed of at the wrong sites, such as gutters, open parks, farms, backyards, etc. Although the law does not permit these practices, they have become a negative social behaviour due to the absence of education, unsatisfactory or unreliable waste management services, and enforcement of such unlawful waste disposal practices, primarily in urban areas.
- Reuse Initiatives: Few organisations and agents currently build a business model around specific waste. Organisations like Revival Earth focus on repurposing textile waste. Many of these initiatives have their collection methods, but they do not collect significant volumes compared to the waste generated.

3.8 Understanding the Gap between Local and International Regulations and Policies

In conversation with Leticia Abra-Kom Nyaaba, Ag. Director of Ghana National Cleaner Production Centre (GNCPC) -EPA, the Environmental Assessment Regulations, 1999 (LI 1586), is a key legal framework in Ghana. This legislative instrument ensures exporters and importers have guidelines that regulate and prevent Ghana from becoming a dumping ground. Ghana's waste crisis is partially due to a lack of infrastructure, systems, etc. However, a more significant 'root' cause is excessive volumes from high consumption elsewhere, exported to Ghana. This makes it a shared responsibility to manage the burdens of these waste materials dumped into Ghana from the Global North. Furthermore, this act illustrates the unfair distribution of external textile waste, making it difficult for the country to find an independent solution.

The following are a few identified strategies that could help curb the textile waste crisis.

- International Regulations: Exporting countries often impose restrictions to ensure high-quality goods are donated or sold as second-hand. Receiving countries are not involved in determining the qualification, which has local resonance. Michael Oppong, chairman of KUCSA (Oppong, M, personal communication, October 2024), expressed interest in engaging sorting agents

in sending countries to work closely to develop a guide and a framework to enforce.

- **Policy Enforcement:** Ghana has weak local regulatory frameworks that allow unacceptable practices under international norms. The study highlighted concerns about implementing the existing LI 5686 and other initiatives in line with protecting our environment. The researcher believes it is a matter of prioritisation by the lawmakers and enforcers. Ghana, in collaboration with all stakeholders, can curb textile waste just as they did in the e-waste initiatives. The LI would have to be reviewed to reflect today's concerns and draw up an implementation roadmap, committing stakeholders and enforcers.

3.9 Critical Infrastructure Gaps

Several infrastructural gaps hinder the efficient functioning of circular ecosystems in the second-hand clothing business in Ghana:

3.9.1 Lack of Recycling Facilities

- **Insufficient recycling infrastructure:** The total number of recycling plants and facilities in Ghana cannot be confirmed. However, it is evident that they are insufficient. For instance, in the Greater Accra region, with the highest population in Ghana, there are only two major facilities: the Accra Compost and Recycling Plant (ACARP) and the Integrated Recycling and Compost Plant (IRECOP). (acarp.com) This limited capacity leads to operational challenges for waste management companies. For instance, firms like Zoomlion and smaller waste collectors often struggle to adhere to collection schedules. The scarcity of processing facilities means that waste trucks sometimes cannot be emptied for days, causing delays in waste collection from residences and establishments. (myjoyonline.com)
- **Lack of effective waste management systems:** A well-structured waste management system is organised and efficient. However, there are no efficient waste management systems. For instance, in Kantamanto, like most typical institutions in Ghana, there are few or no waste collection points, and the waste is not segregated.
- **Absence of centralised waste collection and sorting points within markets:** Most markets in Ghana have few or no centralised waste collection points. As a result, people dump waste wherever they find it convenient. For our study, it was noticed that there were no designated bins at Kantamanto, and a dumping site was hardly visible.

3.9.2 Limited Repair and Upcycling Centres

- Few dedicated spaces for professional repairs or creative upcycling: Given the vast population of Accra (approximately 5.5 million, Ghana Statistical Services—2022), there are too few upcycling facilities to tackle the waste output. Within the Kantamanto community, even the repairers are fewer than the traders and always have a considerable workload. Due to that challenge, the repairers always work longer hours to increase their efficiency and meet the traders' demands for repairs and upcycling.

Repair workshops often lack modern tools. In interactions with selected repairers and observations during our research, we noted that most repairers do not possess the appropriate or advanced tools to work efficiently. Many attributed this challenge to the high cost of equipment and a lack of support from the local government. They also emphasised that the work was not profitable enough to justify procuring modern equipment.

3.10 Social and Environmental Impact

3.10.1 Social Impact

Employment Opportunities: Based on observations and interviews with the chairman of the Used Clothing Sellers Association, it is clear that Kantamanto and the SHC market possess a considerable workforce and significant potential for job creation. This sector includes a diverse range of trades and roles, emphasising the opportunities available. There are various avenues for job creation, including property rentals, savings and loans, security services, and thrifting, among others.

Affordable Clothing: Second-hand trading offers low-cost alternatives, making clothing accessible to low-income populations. In countries like Ghana, where the majority of the population is within the middle-to-low class income range, the majority cannot afford new clothing regularly from luxury shops and malls, as clothes are very expensive. Second-hand trading offers affordable options for the average Ghanaian.

3.10.2 Environmental Impact

Positive Environmental Impacts

Reduction in Textile Waste: Second-hand clothing extends the lifecycle of garments by adopting reuse and recycling methods. Some damaged SHC may be suitable for downcycling into materials like Refuse-Derived Fuel (RDF), sofas, etc. This aligns

with the principles of a circular economy, which prioritises sustainability over waste. It encourages a circular economy culture and helps address textile waste.

Lower Resource Consumption: Reusing existing clothing will lower the demand for new clothing production, reducing the consumption of resources like water, energy, and raw materials.

Decrease in Carbon Footprint: Industrial clothing production releases greenhouse gases, especially in energy-intensive processes like dyeing. In Ghana, over 60% of clothing sold is second-hand, impacting the demand for locally produced clothing and textiles (Brooks 2013). The decreased demand means lower industrial production, reducing the rate of carbon emissions.

Negative Environmental Impacts

Waste Challenges: Inadequate waste management pollutes land and waterways. Archetypes like activewear and outerwear contain a high percentage of synthetic materials, which contribute to non-biodegradable waste. When such items are discarded, they take years to decompose, releasing microplastics into the environment. These items also contribute to air pollution due to open-air incineration.

Carbon Emissions: The global trade of second-hand clothing often involves long shipping distances, contributing to carbon emissions, especially for exports to developing countries.

Overburdening Developing Countries: As revealed in the early parts of this report, import volumes are high, exceeding demand (in the case of Ghana). This overburdens our waste systems, as infrastructure and technology are limited.

Conclusion

This study acknowledges that Ghana's textile waste crisis results from both internal and external factors. However, due to the scope and research context, the focus was placed on external contributors, particularly the importation of second-hand clothing (SHC) from the Global North. These imports have become a significant and traceable source of waste, as traders report an increasing volume of unusable garments in imported bales. This makes the issue of SHC imports central to understanding and addressing the broader textile waste problem in Ghana.

The findings reveal critical gaps in policy enforcement, such as the ineffective application of existing regulations like LI 1586, and the lack of a coordinated national framework to monitor and control SHC imports. Moreover, weak infrastructure, limited financial investment, and poor public awareness continue to hinder effective waste management. The underdeveloped recycling industry and reliance on a single waste contractor (Zoomlion) further compound the issue, leading to environmental degradation and health risks due to open dumping and burning.

To mitigate the crisis, the study recommends strengthening institutional collaborations and international collaborations. This includes engaging relevant agencies such as AMA, GSA, Ghana Customs Service, and the EPA to review, expand and implement LI 1586 as a comprehensive framework. International cooperations should also be fostered to secure financial and technical support for infrastructure development. The introduction of mechanisms such as bale verification tags, proposed by the EPA, could improve quality control and reduce waste at the point of entry.

Furthermore, the government is encouraged to promote a circular economy approach, support private sector participation, and create incentives for recycling and upcycling initiatives. Widening partnerships with waste management companies, launching public education campaigns, and developing sustainable market practices are crucial steps towards creating a responsible waste management culture.

Ultimately, addressing Ghana's textile waste crisis requires a multi-stakeholder, systems-based approach that combines policy reform, international collaboration, public awareness, and investment in sustainable solutions.

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Institutional Factors Influencing ESG Risk in the Energy Services Industry – A cluster approach

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Abstract: Different companies listed on stock exchanges are declaring their non-financial reports alongside their financial statements, aiming to provide more detailed and substantial information on environmental, social, and governance (ESG) issues. Based on this, the risk associated with these three dimensions is also assessed. This paper examines the possible effect of certain institutional factors—such as political, economic, social, educational, and technological aspects—on the ESG risk of companies operating in the energy services industry. The results indicate that some macroeconomic factors of a country, such as legal regulations for employee protection, competitiveness, market concentration of firms, the human development index, and the percentage of GDP spent on research and development, influence the quality of non-financial reporting and ESG risk. This implies that companies operating or headquartered in countries or regions with more favorable institutional factors tend to exhibit a better approach to environmental, social, and governance issues, resulting in lower ESG risk.

Keywords: ESG risk, institutional factor, energy service industry

1 Introduction

In contemporary corporate governance, non-financial reporting has gained prominence as an essential instrument for conveying information on a firm's environmental, social, and governance (ESG) performance. These disclosures serve not only as a transparency mechanism but also as a strategic communication tool for engaging a

broad spectrum of stakeholders, including investors, regulators, and civil society. ESG risk—defined as the potential for adverse effects stemming from a firm’s environmental practices, social impact, or governance structures—has become an essential point in evaluating long-term corporate sustainability and resilience.

Global ESG rating agencies have developed standardized frameworks to quantify and compare ESG risk across firms and industries, thereby facilitating informed decision-making in capital markets. For publicly listed entities, compliance with ESG disclosure obligations has transitioned from voluntary reporting to regulatory imperative, especially in jurisdictions with progressive sustainability requirements.

The determinants of ESG risk are multifaceted, encompassing both endogenous variables (e.g., corporate policies, managerial competencies, and internal risk controls) and exogenous influences (e.g., macroeconomic conditions, regulatory frameworks, and societal expectations). Within this analytical duality, institutional factors—such as the strength of legal institutions, enforcement mechanisms, and the prevailing norms governing corporate behavior—have emerged as critical in shaping the ESG risk landscape.

This study explores the extent to which institutional factors influence the ESG risk distribution of firms operating in the energy sector. Given the sector’s inherent exposure to environmental externalities, regulatory scrutiny, and socio-economic sensitivity, understanding the institutional underpinnings of ESG risk is imperative for developing effective policy interventions and enhancing corporate accountability.

2 Literature review

2.1 Sustainability and ESG accounting

ESG reporting refers to the systematic disclosure of a firm’s performance and practices concerning sustainability dimensions, such as environmental (E), social (S), and governance (G) factors. It aims to enhance transparency and accountability for stakeholders by providing standardized and comparable information on how a company manages non-financial issues that may impact long-term value creation [15]

ESG risk, on the other hand, refers to the exposure of a company to environmental, social, or governance factors that could materially impact its financial performance or reputation. ESG risk ratings, often provided by agencies such as Sustainalytics, MSCI, or Refinitiv, assess how vulnerable a firm is to ESG-related incidents or systemic issues and how well it manages these risks. High ESG risk may indicate poor practices, inadequate governance structures, or failure to address stakeholder concerns, which can result in regulatory penalties, reputational damage, or financial losses.

Although conceptually distinct, ESG reporting and ESG risk are closely interrelated. Transparent and high-quality ESG reporting can contribute to lower ESG risk by signaling robust risk management practices, improving investor confidence, and demonstrating regulatory compliance. Conversely, poor or non-existent ESG disclosures may elevate a firm's perceived ESG risk due to a lack of verifiable information regarding its non-financial performance [32][9].

2.2 Institutional factors and ESG risk

Scholars have consistently emphasized that national institutional environments play a critical role in shaping organizational behavior by establishing the "rules of the game" that influence the efficiency and legitimacy of organizational structures [9]. In the context of sustainability, empirical research has demonstrated that an organization's country or regional origin significantly affects the **adoption** [6][21], **scope** [7][15][32], and **quality** [40] of sustainability reporting practices. These differences are largely attributed to variations in institutional characteristics across countries, including legal and political systems, economic and financial structures, socio-cultural norms, and education and labor systems (see also [15]; [21])

Country-level institutional factors influence the publication of integrated reports[21]. Their findings highlighted the significance of variables such as investor and employment protection laws, the extent of market coordination and ownership concentration, levels of socio-economic development, national corporate responsibility norms, and underlying societal value systems as key determinants of reporting behavior.

Regarding the literature review, the study tents to explore the relationship between institutional factors and ESG risk. The hypotheses are organized around six institutional domains: politics and law, economics and finance, society and culture, technology and innovation, education and labor, and sustainability. The first four categories align with established national institutional frameworks commonly discussed in institutional theory [21] [26]. It further advances with the literature review by integrating two additional institutional domains—technology and innovation, and sustainability—which have been empirically linked to organizational sustainability outcomes [17] [21] [37].

2.2.1 Politics and law

Political and legal systems significantly shape organizational strategies and sustainability outcomes, with the degree of influence varying by legal tradition. In civil law countries, stronger political involvement in economic and accounting matters fosters broader expectations for corporate transparency and stakeholder responsibility [21] [22]. In contrast, common law countries exhibit weaker political influence, leading firms to prioritize shareholder interests over broader stakeholder concerns

[23][24]. Thus companies operating in the civil law countries tend to show lower ESG risk comparing with the latest ones.

To examine the link between ESG risk and political-legal systems more thoroughly, the analysis also considers the social and environmental dimensions of legal protection and public policy. The assumption is that in countries where social issues (e.g., labor rights) and environmental concerns (e.g., pollution reduction) are highly prioritized, political and legal frameworks are more likely to enforce robust protections in these areas [20] [21]. Consequently, organizations in such contexts may experience stronger institutional and societal pressure to address sustainability issues, which can enhance both their sustainability performance [1][18][30] and their commitment to sustainability disclosures, minimising ESG risk.

2.2.2 Economics and finance

[21][11] state that sustainability reporting practices are influenced by the level of economic development in an organization's country of origin. Economically advanced countries often exhibit stronger institutional frameworks and greater societal capacity to support sustainability initiatives [19]. As a result, organizations in these contexts are more likely to possess the necessary resources for sustainability efforts [5] and as a result derive lower ESG risk. Therefore, it is hypothesized that higher economic development positively influences the extent of ESG risk.

Furthermore, the authors propose that economic freedom may also influence sustainability reporting. Prior research suggests that, when combined with supportive contextual factors such as a strong national sustainability culture, economic freedom can positively impact a country's overall sustainability performance [35]. In this regard, economic freedom may serve as an enabling condition for enhanced sustainability performance [11] [21], as it can mitigate corruption and foster corporate accountability toward social welfare [5], implicating that higher levels of economic freedom are associated with lower ESG risk. With regard to financial systems, the authors differentiate between market-based and bank-based systems. In market-based systems—characterized by high levels of market coordination—companies rely on a broad base of financial stakeholders [21]. These stakeholders independently assess corporate disclosures and make investment decisions accordingly, incentivizing firms to publicly report on their overall performance, including sustainability efforts, to attract support and maintain legitimacy.

Conversely, in bank-based systems, where market coordination is comparatively lower, banks serve as primary financial intermediaries. Due to their influential role and direct access to corporate information, banks are well-positioned to internally monitor company performance [10]. As a result, firms in bank-based contexts face reduced external pressure to disclose performance data publicly, including sustainability-related information and performance [3], hence tempting to show lower ESG risk score.

2.2.3 Social development

A country's social development plays a critical role in advancing the other two pillars of sustainable development: economic growth and environmental protection [36]. In this context, the study focuses on two key dimensions of social development—human development and civic engagement.

Human development has been empirically linked to positive economic outcomes, reduced levels of corruption, and greater female participation in the labor force [2][38][27]. The higher levels of human development and civic engagement positively influence the extent of SDG reporting, as socially advanced societies are more likely to foster public accountability, inclusive policies, and stakeholder expectations for transparent sustainability performance and as consequence we expect lower ESG risk.

Civic engagement has been consistently linked to sustainability outcomes [13][14] and is even regarded as a fundamental component of sustainability itself [31]. In line with this view, civic engagement is identified as a highly influential factor in determining the level of CSR adoption across countries [16]. Building on this evidence, it is suggested that civic engagement may also significantly impact the reduction of ESG risk.

2.2.4 Technology and innovation

It is assumed that organizations operating in countries with higher levels of innovation and technological capability possess greater knowledge resources to support the adoption of sustainability practices aligned with the SDGs [21]. Research has shown that R&D efforts are positively associated with CSR activities, as developing sustainable production systems often requires technological innovation [4][17]. Countries with strong innovation performance are also more likely to lead in sustainability-focused technological advancements [28]. As innovation infrastructure and intensity drive the flow of sustainable technologies over time [12][28], firms in such environments may be more inclined to engage in lower ESG risk.

2.2.5 Education and labor

Research in the fields of CSR and business ethics has demonstrated that education significantly shapes individuals' attitudes, perceptions, and expectations regarding responsible business conduct [8][34]. Individuals with higher education levels tend to exhibit deeper understandings of CSR [33]. At the national level, higher education attainment is also positively associated with environmental sustainability [29]. Based on these findings, it is hypothesized a negative relationship between education and ESG risk. It is verified that organizations in countries with greater investment in tertiary education are more likely to engage with emerging research and adopt innovative sustainability management frameworks [21], and as a result this study suggests also lower ESG risk.

With regard to the labour system, the authors affirm that a high density of trade unions within a country is positively associated with greater employee participation in decision-making processes [21]. Based on this, we may argue that enhanced employee involvement and socio-political progress may foster stronger organizational sensitivity toward the Sustainable Development Goals (SDGs) and a better ESG performance and lower ESG risk.

2.2.6 Innovation

Prior research [21][39][22], argue that a country's overall level of corporate responsibility, environmental performance, and sustainable development can significantly influence the sustainability performance of its organizations. This relationship may stem from the impact of national regulations and cultural norms on corporate sustainability practices. Accordingly, the authors assume that higher national standards in these areas are also positively associated with the extent of SDG reporting. At the same time regarding the sector of energy services, the environmental performance of a country can especially put these national standards, which can, at a certain extent impact the ESG risk of the company

3 A Cluster Analysis

3.1 Methodology and dataset

In this study we take the data for the energy sector, extracted from Sustainalytics.com on 20th March 2025, consisting in 93 firms, from 22 various countries, regarding their ESG risk. Institutional factor data is retrieved from the sources as in the table.

Institution	Institutional Factor	Description	Source
Political/law	POL_law	Common/Civil law	La Porta et al. (1998)
	POL_empl	Employee protection	OECD (2022)
	POL_env	Environment protection stringency	OECD (2022)
Economy	ECON_gni	GNI	OECD (2022)
	ECON_HHI	Market Structure HHI	World Bank (2022)
	ECON_Free	Economic Freedom	The heritage Foundation (2022)
Social	SOC_HDI	Human Development Index	United Nations Development Program (2022)
	SOC_civic	Ivic Engagement	OECD (2022)
Technology/Innovation	TECH_RD	Company R&D % of GDP	World Bank (2022)
	TECH_Innov	Innovation Capacity	World Economic Forum (2022)
Education/Labor/Sustainability	ED_ed	Education level	World Economics
	ED_tertiary	Spending on tertiary education	OECD
	LAB_TU	Trade Union density	OECD
	SUST_env_perf	Environmental performance	Yale University

Figure 1
Institutional factors

We use the 2 step cluster model, trying to create clusters using the BIC criterion (**Bayesian Information Criterion**) to evaluate the goodness of fit of the model and to generate the optimal number of clusters. After creating the clusters, we identify the components which vary more between clusters, trying to create a profile for the generated groups. As a last step we test if ESG risk score does significantly differentiate between these clusters.

3.2 Results

The two step cluster model generates two clusters, with a size ratio of 1,26 (44.3%: 55.7%), in a good model quality. From the modelview we can identify the variables that play the most important role in positioning between the two clusters.

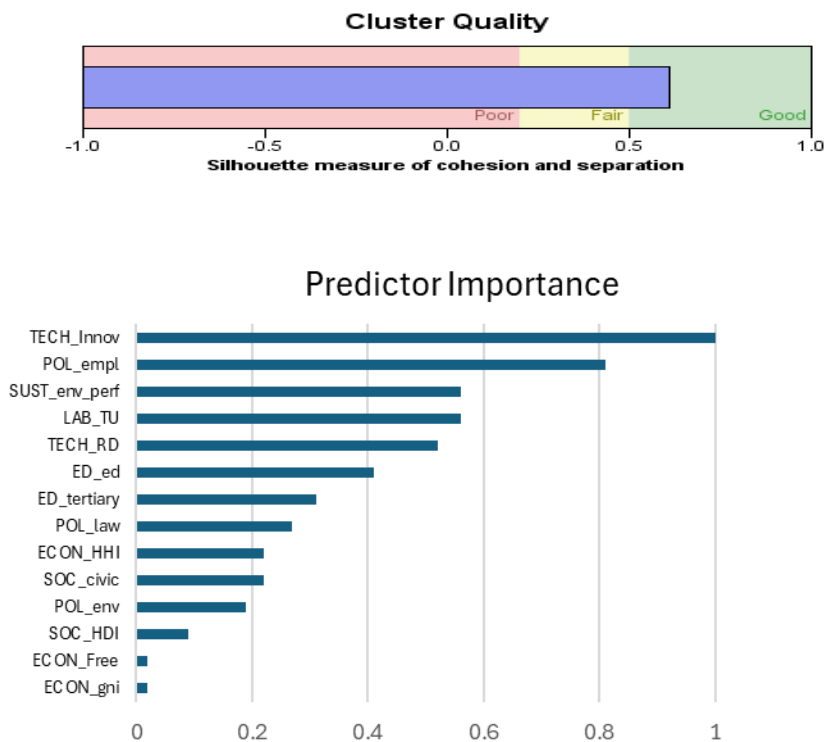


Figure 2
Model quality and predictor importance

The cluster analysis indicates that variables such as innovation capacity, employee protection, environmental performance, trade union density, research and development expenditures, and educational attainment emerge as the most significant predictors distinguishing the two identified clusters. Conversely, economic indicators—including Gross National Income (GNI) per capita, economic freedom, and market structure—exert a comparatively minimal influence on cluster differentiation. Similarly, social dimensions, represented by the Human Development Index (HDI) and civic engagement metrics, do not substantially contribute to the separation between clusters.

Based on the importance of these predictors, the first cluster predominantly comprises companies operating within the energy services sector, situated in countries characterized by a higher capacity for innovation and substantial investments in research and development. These nations also exhibit robust employment protection frameworks, superior environmental sustainability performance, greater trade union density, and elevated levels of educational attainment, including increased spending on tertiary education. Collectively, these factors suggest that the first cluster is defined more by technological, political, environmental, and educational dimensions than by purely economic or social indicators. To assert if the ESG risk score is significantly

lower in cluster one, with the features dimension described above, we apply t-test for independent groups.

Group Descriptives

	Group	N	Mean	SD	SE	Coefficient variation	Mean Rank
ESG_rate	1	31	24.029	6.133	1.102	0.255	35.065
	2	39	28.287	5.378	0.861	0.190	54.449

Independent Samples T-Test

	Test	Statistic	df	p
ESG_rate	Student	-3.092	68	0.001
	Mann-Whitney	346.000		0.001

Figure 3
ESG difference between clusters

Since $\text{sig} < 0.05$, we reject the null hypothesis, stating that cluster one has significantly a lower ESG risk score than the second cluster.

Conclusions

Environmental, Social, and Governance (ESG) risk is shaped not only by a firm's internal practices but also by the broader institutional, legal, and socio-economic context of the country in which it operates. National-level characteristics play a crucial role in either mitigating or amplifying ESG-related vulnerabilities.

Legal institutions, such as the rigorosity and enforcement of employee protection regulations, as well as whether a country follows a common or civil law tradition, have significant implications for corporate accountability, thereby influencing ESG performance and lowering ESG risk. Labor and education, including the density of trade unions and the extent of educational attainment across the population, particularly investments in tertiary education, further contribute to uphold responsible business conduct and low ESG risk. In addition, technological and environmental investments notably in research and development (R&D) and in proactive environmental management are essential prerequisites for reducing ESG risk. Firms operating in countries with high innovation capacity and strong environmental

performance metrics tend to be better equipped to align with ESG standards and adapt to sustainability-driven market and regulatory expectations.

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Strengthening the Position of Farmers in the Dairy Value Chain in Light of the EU Common Agricultural Policy (CAP): Insights from Albania

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Abstract: This article analyzes the position of Albanian dairy farmers within the value chain by assessing their power in price negotiations, access to markets, and integration with processors and retailers. Using the framework of the EU Common Agricultural Policy (CAP), which aims to strengthen farmers' positions in the value chain, the study evaluates how Albanian dairy farmers align with these objectives and identifies key challenges. The analysis highlights structural weaknesses, such as fragmented production, weak bargaining power, and limited access to financial and technological resources, which hinder competitiveness. The study aims to identify ways to empower farmers within the dairy value chain by leveraging policies and programs provided by the European Union, particularly the "Farm to Fork" Strategy. Through a comprehensive approach implemented in the framework of the project "Farm to Fork Academy for Green Western Balkan-our common European future" financed by EU, involving focus group discussions, interviews with key stakeholders, and secondary data analysis, the study provides an in-depth assessment of the current state of the sector and the positioning of farmers within the value chain. Furthermore, it offers concrete recommendations to enhance farmer cooperation, improve quality standards, and implement fair trading mechanisms. The study suggests that government and international partners should support investments in infrastructure and technology, including the establishment of milk collection centers and advanced dairy farm equipment. Additionally, fostering farmer cooperatives would strengthen their bargaining power and improve access to financing and markets. If the right policies are implemented with full support from the EU and national stakeholders, the dairy sector has the potential to increase rural incomes, enhance the quality of life in rural areas, and contribute to overall economic development. Recommendations focus on policies that could enhance farmers' roles in the value chain, including cooperatives, improved market access, and better financial instruments.

Keywords: agriculture, dairy sector, value chain, Albania

1 Introduction

Albania's agriculture remains one of the country's principal economic pillars, contributing around 18% to the Gross Domestic Product (GDP) and providing employment for a significant portion of the rural population. The agricultural landscape in Albania is characterized by approximately 350,000 farms with an average farm size of 1.2 hectares. These farms are often highly fragmented—divided into three to five separate parcels—which poses serious challenges for mechanization, operational efficiency, and overall production effectiveness. Despite the inherent challenges due to fragmentation and small-scale production, Albania's agricultural sector has experienced notable improvements in recent years. This progress is largely attributed to both internal investments and robust international support, particularly through European Union (EU) initiatives such as the IPARD program. These efforts have resulted in better infrastructure, enhanced access to modern technology, and improved market connectivity. The gradual shift from traditional production methods toward more sustainable, modern practices is opening new avenues for increasing productivity and competitiveness in both domestic and export markets.

Within this broader agricultural context, dairy sector stand out due to the significant impact on rural incomes and economic development: The dairy sector is a key contributor to Albania's livestock production. It is critical for the direct income of rural families and for ensuring local food security. However, it faces numerous challenges such as low average yields, inadequate cold storage facilities, and insufficient organization among farmers.

The government's focus on strengthening the position of farmers in the value chain is a central element of the Common Agricultural Policy (PPB) for 2023–2027, particularly through Objective 3, which emphasizes enhancing negotiating power, boosting competitiveness, and promoting better organization among farmers. This policy framework advocates for improved synergy within the value chain, market orientation of production, and increased transparency, all of which are crucial for enabling farmers to secure fair prices and sustainable incomes. The overarching goal of this paper is to identify the challenges that hinder dairy farmers from positioning themselves more effectively within the value chain. It also aims to evaluate the opportunities offered by EU policies and funding mechanisms and to propose specific interventions that bolster the technological and negotiating capacities of these producers.

The Common Agricultural Policy (CAP) of the European Union (EU) for 2023-2027 outlines several key objectives, including Objective 3: "Strengthening farmer position in food chain"². This objective focuses on creating conditions that enable farmers to

² European Commission (2022). Common Agricultural Policy. Specific objectives of the CAP. Accessed from https://agriculture.ec.europa.eu/sustainability/economic-sustainability/cap-measures_en#

enhance their bargaining power, increase competitiveness, and improve organization in their interactions with processors, traders, and exporters. The intervention measures under this objective are linked with: a) strengthening cooperation among farmers, b) enhancing synergies within value chains, c) supporting the development of market driven production models, d) fostering research and innovation, e) increasing market transparency, and, f) ensuring effective mechanisms against unfair trading practices.

2 Objectives and Methodology

The study is structured around several specific objectives:

- To evaluate the production capacity, organizational structure, and main challenges of dairy farmers.
- To investigate factors affecting farmers' bargaining power—including input costs, quality standards, and group organization—and understand how these affect overall profitability
- To examine how the “Strengthening the Position of Farmers in the Food Value Chain” objective of the Common Agriculture Policy (CAP) can be practically implemented, especially in the context of fragmented farm structures in Albania.
- To provide a basis for targeted recommendations to address main challenges faced by the dairy value chain stakeholders.

This study adopted a sequential, mixed-methods design that wove together qualitative fieldwork and quantitative secondary-data analysis to capture both the lived experience of Albanian dairy farmers and the structural forces that shape their bargaining position. We began with a scoping exercise in early 2024, mapping all relevant actors—from smallholders and collectors to processors, input suppliers, and policy-makers—and refining the research questions through informal conversations and a review of national policy documents. The exercise produced a stakeholder matrix that later guided purposeful sampling in the field.

Primary data were gathered between September and December 2024. Thirty five semi-structured interviews (average length one hour) were conducted with 20 farmers of varying herd sizes, five processors, three input suppliers, two Ministry of Agriculture and Rural Development officials and five experts .To explore group dynamics and surface shared concerns, we organized three focus-group discussions in Tiranë, Lushnjë and Berat, with participation of around 30 participants in total stratified by farm size and gender. In addition, a Workshop at national level brought producer organizations, processors' associations, extension officers, NGOs and EU-project staff to the same table, allowing us to test preliminary findings and discuss the feasibility of proposed interventions. All sessions were recorded with informed consent, transcribed

verbatim, anonymised and stored in an encrypted repository that also contains our reflexive field notes.

Parallel to the fieldwork, we compiled a longitudinal quantitative dataset that merges INSTAT agricultural statistics (2000-2023), Ministry of Agriculture and Rural Development subsidy records (2019-2024) and international sources such as the FAO, World Bank and EU Market Observatory. We also assembled a policy corpus covering the CAP Strategic Plan 2023-27, the Unfair Trading Practices Directive, IPARD III guidelines and key national support schemes (e.g., Albanian Governments :Decrees VKM 130/2024 and VKM 581/2024).

Quantitative insights were merged in a SWOT matrix that stakeholders scored for likelihood and impact during a feedback workshop, helping to prioritize strategic options. Finally, triangulation across data types and actor groups ensured that divergent perspectives were reconciled; any anomalies were followed up through four short telephone calls with the relevant respondents.

Key issues discussed during focus groups

For the value chain analysis of the dairy sector, a list of semi-structured questions was developed to identify the key challenges and opportunities influencing the performance of farmers and other stakeholders, with a particular focus on farmer's position in the value chain. Key questions that guided this process include the following:

1. What are the main challenges confronting farmers in the value chain?
2. How can farmers strengthen their position in the value chain to add value to their products?
3. Is it feasible for farmers to negotiate better conditions with other value chain actors, particularly regarding pricing and production?
4. Is it realistic for farmers to influence decision-making within the value chain regarding the value of the product?

The methodological steps followed are detailed in the Table 1

Phase	Activity	Purpose	Main Outputs
1	Scoping & stakeholder mapping	Identify key actor categories (farmers, processors, collectors, input dealers, policy-makers) and refine research questions.	Stakeholder matrix; interview & focus-group guides.
2	Primary data collection • Semi-structured interviews • Focus groups • Consultative meetings	Elicit first-hand perceptions of constraints, opportunities, and power relations.	28 interview transcripts; 3 focus-group recordings; 5 consultative-meeting minutes.
3	Secondary-data compilation	Assemble time-series on herd size, milk output, prices, subsidies, and policy measures from INSTAT, MARD, EU, FAO, and World Bank sources.	Harmonized dataset (2000-2024); policy document library.
4	Analytical synthesis • Descriptive statistics • Thematic coding • SWOT analysis	Quantify performance trends; distil cross-cutting themes; assess strengths, weaknesses, opportunities, threats.	Value-chain map; SWOT matrix; evidence tables.
5	Triangulation & validation	Cross-check findings across data types and stakeholder groups; present preliminaries in a feedback workshop.	Revised findings; consensual policy recommendations.

Table 1
Research Design and Sequence

Limitations of study

Despite incorporating both primary and secondary data, the study has several limitations. The main challenges include the lack of available statistics for some indicators and the absence of recent data for others. Additionally, the interviews and focus group discussions were based on an indicative sample, which introduces a margin of error in the collected data. Furthermore, some stakeholders were unavailable

for direct interviews, affecting the depth of information gathered. To mitigate these limitations, a complementary analysis of primary and secondary data was conducted.

2 Literature Review

The food value chain plays a crucial role in determining the economic and social sustainability of agricultural sectors worldwide. Understanding farmers' positions within this chain is essential to improving their market access, bargaining power, and profitability. In the context of Albania, the dairy value chain holds significant importance due to its contribution to rural livelihoods and national food security.

The food value chain encompasses all activities involved in the production, processing, distribution, and consumption of food products. According to Kaplinsky and Morris (2001), a value chain perspective helps identify key actors, their relationships, and value-added activities at each stage. Porter (1985) highlights the importance of competitiveness and efficiency within value chains, emphasizing the need for upgrading strategies.

Studies by Gereffi et al. (2005) distinguish between producer-driven and buyer-driven value chains, which are critical in understanding power asymmetries in agricultural markets. The food value chain in developing countries often suffers from inefficiencies related to infrastructure, financial constraints, and lack of market linkages (Trienekens, 2011). In Albania, similar challenges affect the agrifood sector, requiring policy interventions to enhance competitiveness and sustainability (FAO, 2019).

Farmers' positions in the food value chain are influenced by factors such as access to inputs, market power, institutional support, and bargaining capabilities. Studies by Barrett et al. (2010) and Swinnen and Maertens (2007) suggest that smallholder farmers often face disadvantages in global value chains due to limited access to technology, finance, and information.

In Albania, research indicates that farmers struggle with low bargaining power and are often price takers due to fragmented production systems and weak cooperative structures (World Bank, 2020). Strengthening farmers' roles through collective action, contract farming, and value chain integration has been proposed as a solution to enhance their market participation (Gellynck & Kühne, 2008).

Market power :The food supply chain in the EU is characterized by high levels of concentration among retailers and processors, leading to asymmetries in market power. Research by Hendrickson et al. (2018) highlights the challenges that farmers face when negotiating prices due to the dominance of large supermarkets and agribusiness corporations. The EU's response includes competition law enforcement, aiming to prevent monopolistic behaviors that undermine farmers' profitability (Bonanno & Lopez, 2014).

Another crucial aspect of EU policy is price transparency. The EU Market Observatory for agricultural markets provides farmers with real-time data on market prices and trends, improving their ability to make informed production and marketing decisions (European Commission, 2022). Transparency initiatives such as these are linked to reduced price volatility and better income predictability for farmers (Tothova, 2011).

2.1 EU Policy Framework

European Union (EU) has established a comprehensive policy framework aimed at improving farmers' positions within the food value chain. These policies focus on increasing transparency, strengthening market power, and ensuring fairer distribution of value. The Common Agricultural Policy (CAP), competition law, and specific legislative measures such as the Unfair Trading Practices (UTP) Directive play a crucial role in shaping the dynamics of agricultural markets. The EU's Common Agricultural Policy (CAP) serves as the cornerstone of agricultural policy in Europe, aiming to ensure fair incomes for farmers, food security, and rural development (European Commission, 2021). The CAP's latest reforms emphasize market orientation, sustainability, and direct support schemes to enhance farmers' economic resilience.

One of the key components of the CAP is the strengthening of Producer Organizations (POs) and Cooperatives, which enable farmers to consolidate their bargaining power in negotiations with processors and retailers (Swinnen, 2015). Moreover, CAP reforms promote risk management tools, including insurance schemes and income stabilization mechanisms, to support farmers against price volatility and external shocks (Matthews, 2018).

The EU has also implemented the Unfair Trading Practices (UTP) Directive (EU Directive 2019/633), which addresses power imbalances in the food supply chain. The directive prohibits unfair practices such as late payments, unilateral contract changes, and last-minute order cancellations, thereby ensuring fairer treatment for farmers (European Commission, 2020). Studies indicate that such measures significantly improve farmers' negotiating positions and income stability (Crespi & Saitone, 2019).

3 Current Situation in dairy sector

The dairy sector is a cornerstone of Albania's agricultural system and plays a crucial role in both local food consumption and export potential. Livestock production—notably milk and meat—constitutes a major component of the country's agro-industrial chain, with dairy products representing an essential element of the national food supply. According to unpublished data from the Ministry of Agriculture and Rural Development, the livestock segment contributes around 45% of the overall value of Albanian agriculture.

Over the past decades, there has been a significant decline in the number of livestock. Data covering the period from 2000 to 2023 indicate a cumulative reduction of approximately 48% for cattle, 30% for sheep, and 36% for goats. Even when focusing on the more recent period (2019–2023), the declines remain considerable: cattle numbers fell by about 27%, sheep by 20%, and goats by 24%. These trends underscore the urgent need for targeted interventions to address the challenges threatening the sustainability of livestock production.

Milk production in Albania has experienced both significant growth and notable decline over the years. From 1990 to 1996, total milk production nearly doubled—from 517,000 tons to 1,044,000 tons—reflecting favorable conditions and improvements in agricultural practices during that period. The production peaked at 1,156,000 tons in 2017, but thereafter it began to decline, reaching 901,000 tons by 2023 (a reduction of approximately 22%). Breaking down the numbers by animal type, cattle milk dropped by about 22%, while milk production from sheep and goats decreased by roughly 26% and 20% respectively.

Despite the decline in total production volumes, there is a positive trend in milk yield per animal. The average yield per cow increased substantially—from 1,398 liters in 1990 to 3,157 liters in 2023, which represents an improvement of over 125%. This enhancement in productivity is more pronounced in larger farms that benefit from modern technologies and improved management practices, although small-scale farms still struggle with limited access to such advancements. Milk production by category during 1990-2023 is analysed in the following table

Category	1990	1996	2017	2022	2023	Change in %
Cows	421,000	895,000	983,000	825,000	765,000	-22.15%
Sheep	44,000	70,000	87,000	69,000	64,400	-25.98%
Goats	52,000	79,000	87,000	76,000	70,000	-19.54%
Total	517,000	1,044,000	1,156,000	970,000	901,000	-22.08%

Table 2
Milk production by category during 1990-2023
Source: INSTAT (2024)

3.1 Support for the Dairy Sector in Albania (2019-2024)

The dairy sector is a key pillar of Albania’s agricultural economy, playing a critical role in sustaining rural livelihoods and contributing significantly to the country’s overall food production. Recognizing its importance, the government has implemented targeted support measures for the dairy sector for the period 2019-2024. These measures are designed to enhance productivity, modernize production, and ensure

sustainable development through two main channels: the National Support Scheme and the Investment Scheme.

Under the national scheme, financial support is provided directly based on the “base number” of animals in a herd, with differentiated payments for cattle on one hand and for small ruminants (sheep and goats) on the other

For cattle, particularly those raised for reproduction, the government offers support of up to 10,000 lek per head for farmers with a minimum of 10 cows. However, for herds that exceed 50 head, the benefit is reduced by 50%—unless the farmers are registered as part of a formal cooperative or farmer group. This structure is intended to reward smaller, more efficient operations while encouraging collaboration among farmers. For small ruminants, farmers who own at least 100 head of sheep or goats are eligible for a payment of up to 1,200 lek per head. Similar to the cattle scheme, for herds exceeding 300 head, the benefit is halved unless the farm operates under a recognized cooperative framework. This tiered payment system reflects an effort to balance support across different scales of operation while promoting organized, collective action in the sector

Complementing the direct payments, the Investment Scheme is aimed at modernizing the dairy sector by improving infrastructure and facilitating access to modern technology. This scheme focuses on two primary areas: i) Construction of Facilities:: The government provides financing that covers 50% of the total taxable invoice value for building facilities designed for the expansion and improvement of animal rearing. To qualify, new facilities must meet minimum capacity requirements—specifically, they should be capable of housing at least 10 cows or 100 small ruminants. The maximum benefit available per subject under this scheme is capped at 15,000,000 lek. And ii) Modernization of Equipment::To further support the modernization process, the Investment Scheme also covers the purchase of essential equipment and machinery. This includes tools that enhance operational efficiency and improve the overall management of livestock farms. Here too, 50% of the total taxable invoice value is financed, with a maximum cap of 5,000,000 lek per subject.

3.2 Organization of the Dairy Value Chain in Albania

The dairy value chain in Albania is a complex system involving a diverse array of stakeholders who collectively influence the quality, safety, and market price of milk and its by-products. At the core of this chain are the dairy farmers, whose operations vary significantly in scale.

The governance of Albania’s dairy value chain is critical to ensuring high product quality and food safety. The sector involves various stakeholders—ranging from smallholder farmers and cooperatives to private collection centers and processing factories—that must work in close coordination to deliver milk and dairy products that meet established standards.

A central challenge within the value chain is the lack of consistent, long-term relationships between small-scale dairy farmers and large processing companies. Research shows that many small farmers prefer short-term, “spot” transactions, opting to sell their milk to the highest bidder at the time of delivery. In fact, only about 44% of farmers reported having a long-term contract with the same buyer. This instability undermines investments in quality improvements and infrastructure, as neither party feels secure in their ongoing collaboration

In contrast, larger processors, with better financial resources and technological expertise, are able to dictate terms and impose rigorous quality standards on their suppliers. For example, one of the largest processing companies in Berat, “Erzeni,” emphasizes the use of written contracts. These contracts detail the payment terms, hygienic standards (such as acceptable microbial and antibiotic residue levels), and delivery deadlines. Through such agreements, processors can secure a steady, high-quality milk supply, while offering technical support—such as providing milking equipment and veterinary advice—to help farmers meet these standards.

The figure 1 below traces the journey of milk from **farm gate to household table**, highlighting the distinct stakeholders that shape both the flow of product and the distribution of value.

Overall, the figure illustrates a delicate equilibrium. Farms supply the raw material; collectors and processors transform and police quality; distributors, retailers, and traders impose commercial discipline; and consumers signal value. Strengthening weak links—especially cold storage at farm level, cooperative bargaining, and certification support for small processors—could move more of the final retail euro back toward producers, making the Albanian dairy chain both fairer and more resilient.

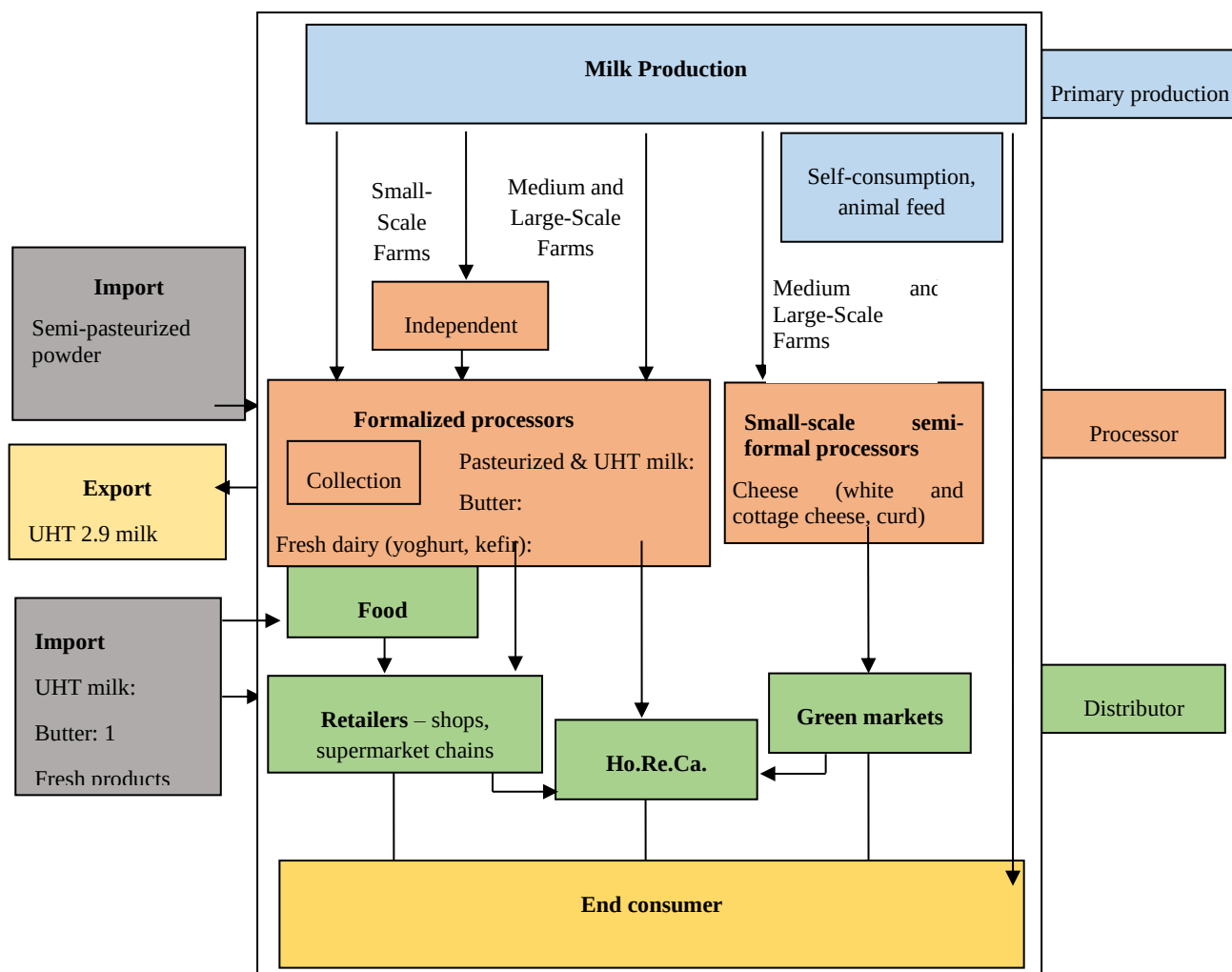


Figure 1
Dairy value chain Map
Source; AGT & DSA. (2021a). Milk Sector Study Report

Example: The AGS Model
 AGS, company, operates in the Durrës, Sukth–Vadardhe regions. AGS employs a dual-contract system that clearly specifies all conditions of cooperation, from minimum milk quantities and quality parameters (microbiological and physico-chemical standards) to payment terms and delivery schedules. AGS works closely with farmers through its dedicated veterinary team, which conducts daily quality checks and provides continuous technical advice. In a five-year partnership with a group of farmers in Baldushku, Tirana, AGS established a centralized milk collection center that has improved both the consistency of supply and the overall quality of the milk received. However, while group contracts can stabilize milk prices, they may also create challenges if one member decides to withdraw, potentially disrupting the entire collective arrangement.

Authors interviews, 2024

4 SWOT Analysis

Strengths (S)	Weaknesses (W)
• Suitable natural and climatic conditions create an ideal environment for producing high-quality milk. • A strong tradition in milk production and traditional dairy products, such as white cheese and cottage cheese, which have a stable market and a good reputation. • Consumer trust and preference for local, fresh, and natural products, especially milk.	• High costs for livestock feed and veterinary services negatively impact farmers' incomes. • Labor shortages due to migration, declining interest among young people, and high labor costs threaten the sustainability of livestock farming. • Lack of cooperation and weak negotiation skills prevent farmers from benefiting from economies of scale and achieving unified market access • Low production levels, reliance on traditional methods, and limited use of modern technologies reduce competitiveness with imports. • The lack of standards and certifications for food safety requirements restricts access to international markets.

	• Difficulties in financing and investment prevent local farmers from keeping up with larger competitors. • Limited knowledge of food safety, standards, and market demand, pricing, and distribution channels weakens farmers' market positioning. •
Opportunities (O)	Risks (T)
• Growing demand for local and organic products in both domestic and international markets presents export opportunities for farmers. • Support from EU programs and rural development funds offers financing opportunities for modernizing equipment, improving standards, and expanding into EU markets. • Investments in technology, such as new processing lines, hygiene equipment, and modern management systems, can enhance productivity and improve product quality.	• Competition from imported products, often offered at lower prices and with established standards, challenges the competitiveness of domestic products. • Climate change and environmental factors can negatively impact production, increasing uncertainty for farmers. • Food safety concerns may lead consumers to prefer products with international certifications, disadvantaging domestic products that lack quality certification. • Bureaucratic procedures and high certification costs create barriers to accessing EU markets. • Operating in an oligopolistic market increases the risk of discriminatory pricing for farmers, limiting their bargaining power.

4.1 Key Findings

High cost of inputs Farmers consistently report that one of the most pressing challenges is the high cost of inputs. These include essential feed components such as soybean mixes and protein supplements, which are critical for animal nutrition. Many farmers produce a portion of their own feed, yet they still need to purchase supplements. Financial constraints make it difficult to benefit from economies of scale, and the limited capacity to purchase inputs in bulk further drives up production costs. Delays in government support—for example, late reimbursement of subsidized fuel—exacerbate these challenges, with one participant noting, “The fuel is reimbursed late; it has lost its value.”

Labor Shortages and Dependence on Family Work:

Another major challenge is the shortage of labor. Due to the emigration of young workers and a general low interest in agricultural jobs, dairy farms are forced to rely heavily on family labor. In many cases, processes that require external labor—especially tasks perceived as unpleasant, like handling manure—are almost entirely neglected. This heavy dependence on family labor not only limits the scale of production but also hinders the adoption of more efficient, modern practices.

Inadequate Milk Storage and Processing Facilities:

Proper milk storage is essential for preserving quality, yet many farmers face significant infrastructural challenges. Without adequate refrigeration, milk quality deteriorates rapidly, forcing farmers to sell at lower prices or rely on immediate, often informal, sales channels. This deficiency in storage infrastructure ultimately leads to losses in both product quality and profitability.

Collective organization and bargaining power :

The lack of cooperatives and farmer associations weakens farmers' bargaining power. During consultation meetings, a lack of cooperation and trust among farmers was evident: *"We don't have unions, we have nothing."* Even where they exist, farmers' unions and associations are often inactive or ineffective: Limited cooperation prevents farmers from influencing decision-making and price setting. They are almost always subject to the prices set by processors, with little control over the final value of milk. This is due to the dominance of a few large processors, the absence of long-term contracts, and the lack of horizontal cooperation among farmers.

On the other hand, *the absence of formal contracts and transparency*

leaves farmers with little or no influence over the terms of sale. Regarding their formal relationships with dairies, farmers report that contracts with collectors are rare: Additionally, weak collective organization prevents the standardization of practices and the establishment of fair mechanisms for value sharing, further disadvantaging farmers in the supply chain.

Insufficient Training and Technical Support:

A recurring theme in the discussions is the limited access to structured training programs. Most training is provided through international projects rather than consistent local institutional support. This gap in technical guidance—ranging from proper milking practices to effective herd management—restricts the farmers' ability to adopt modern technologies and improve the overall quality of their milk. The lack of continuous, locally-driven technical support further hinders innovation and sustainable development.

Limited Acces to finance:

Results from the consultation meetings indicate that government support for farmers in the dairy sector is insufficient to meet the sector's needs and promote its development. Regarding livestock support, farmers consider it inadequate and difficult

to access:. Farmers state that, under these conditions, they are not motivated to increase their livestock numbers and require greater support:. Additionally, some farmers expressed frustration with the investment scheme, particularly regarding difficulties in obtaining construction permits for stables: Many subsidy schemes also require formal documentation that small farms often lack (e.g., licenses, active taxpayer status, proof of ownership). Without these documents, farmers are unable to access support schemes.

Recommendations

Recommendations are designed to address the persistent challenges facing smallholder farmers and to enhance their competitiveness within the value chain. These recommendations are built on an integrated analysis of the current situation, which highlights issues such as high input costs, fragmented production, insufficient infrastructure, weak market relationships, and limited access to finance and modern technology. The overarching goal is to achieve sustainable development and improve the position of dairy farmers through coordinated policy measures and targeted interventions.

Strengthening Cooperative Models and Micro-Collaboration

One key recommendation is the establishment of "micro-models" of cooperation. Small groups of farmers are encouraged to band together to share the costs of essential investments, such as the installation of cooling tanks. By forming these small, organized groups, farmers can lower individual expenses, improve milk quality, and create a foundation for more formal cooperative structures in the future. This model, tested successfully in the Myqejeja Farm project in collaboration with the processor Erzeni, has demonstrated that such an approach not only enhances hygienic standards but also reduces operational costs. In addition, participation in these cooperatives opens access to EU funding instruments like IPARD and national schemes, which can further support modernization efforts.

Promoting Formal Contractual Relationships

Enhancing contractual relationships between farmers and local processors is another critical measure. Currently, many dairy farmers operate on a spot-market basis, leading to unstable prices and uncertain market access. The recommendations call for the promotion of short-term, written contracts between farmers and processors. These contracts should clearly specify payment terms, quality standards (including microbial load, antibiotic residues, and somatic cell counts), and delivery timelines. Pilot projects can help educate farmers on the benefits and specifics of formal contracts, while technical support from experienced partners can ensure that these arrangements are effectively implemented. By stabilizing prices and guaranteeing markets, such contracts would reduce uncertainty and enable both farmers and processors to plan long-term investments with confidence.

Enhancing Training and Practical Support

The report emphasizes that one of the fundamental issues in the sector is the lack of continuous, practical training. To address this, it is recommended that practical field schools be established to transfer essential knowledge and skills. These schools should focus on areas such as ration management, feed planning, and basic accounting. For example, centers like Center for Technology Transfers, operating in the country could host regular training sessions, where farmers can immediately see the benefits of improved practices and begin adopting modern techniques. Such training programs would not only enhance the technical capabilities of individual farmers but also foster greater collaboration and innovation across the sector.

Supporting Value-Added Product Development

To increase the overall value of dairy products, the recommendations stress the need to support initiatives that help farmers add value to their raw milk. This could be achieved through micro-grants that enable family farms to set up basic processing lines—for instance, for the production of cheese or yogurt. Moreover, creating quality seals such as “Local Albanian Milk” would help differentiate domestic products in both local and export markets. Implementing these measures, especially in medium and large farms, can encourage product diversification and even promote agro-tourism, thereby opening new revenue streams.

Easing Access to Finance and Navigating Bureaucracy

A significant barrier for many dairy farmers is the complexity of accessing financial support. The recommendations suggest leveraging Agricultural and Rural Assistance Centers (QABR) to help farmers navigate the cumbersome procedures associated with funding applications. Successful models in regions like Pukë, Kukës, and Dibër have demonstrated that such centers can provide essential administrative and technical assistance. By replicating these models nationwide, the government can improve farmers’ access to critical financial resources, enabling them to invest in modern equipment and infrastructure.

Implementing the "Milk in Schools" Program

Finally, the document advocates for the implementation of the "Milk in Schools" scheme, based on the EU “From Farm to Table” model. This program aims to establish stable, guaranteed markets for local dairy products by ensuring that primary schools are supplied with fresh, locally produced milk. Such a program would not only improve the nutrition of children but also stabilize domestic demand for dairy products, contributing to the broader development of rural economies. Close collaboration among ministries, municipalities, and farmer groups is essential to ensure that this program is successfully implemented and that it benefits all stakeholders involved.

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Mobile app - Can sports clubs now use it effectively?

Case study of the Falco-Vulcano Energia KC Szombathely basketball team

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Abstract: A clear trend today is that screen time is increasing as smartphones continue to proliferate. Sportsclubs are, therefore, also a worthwhile presence in phone apps. Why? The trend also shows that although screen time is increasing, time spent on social media is stagnating. Moreover, mobile apps are a direct way for companies, including sports companies, to reach consumers and fans. Another positive aspect of the app is that, as long as the social media platforms are in the hands of others (Facebook, Instagram, TikTok), the mobile app is fully owned by the developing sports club. We already see many examples of clubs abroad using this tool. Is there a case for it in Hungary? We looked for the answer to this question at the Szombathely basketball team. We looked at the mobile app of the Falco-Vulcano Energia KC team, its access, and possibilities.

Keywords: marketing, sports marketing, mobile applications, digital engagement

1 Introduction

The study of digital habits is of increasing importance, as we are spending more and more time with our phones in our hands [13]; [14]; [15]; [18]; [20]. The use of smart devices is accessible to all age groups, and their impact should be studied, because we use our smart devices and the different applications on them a lot, which can be used for development, recreation, and entertainment [2]; [6]; [18]; [21]. Both national and international trends show that time spent on mobile apps will overtake time spent on

social media [2]; [3]; [16]; [17]; [18]. The above phenomenon is more likely to be observed in the older age group, specifically 13-16 years old, before social media became widespread, as illustrated in Figure 1.

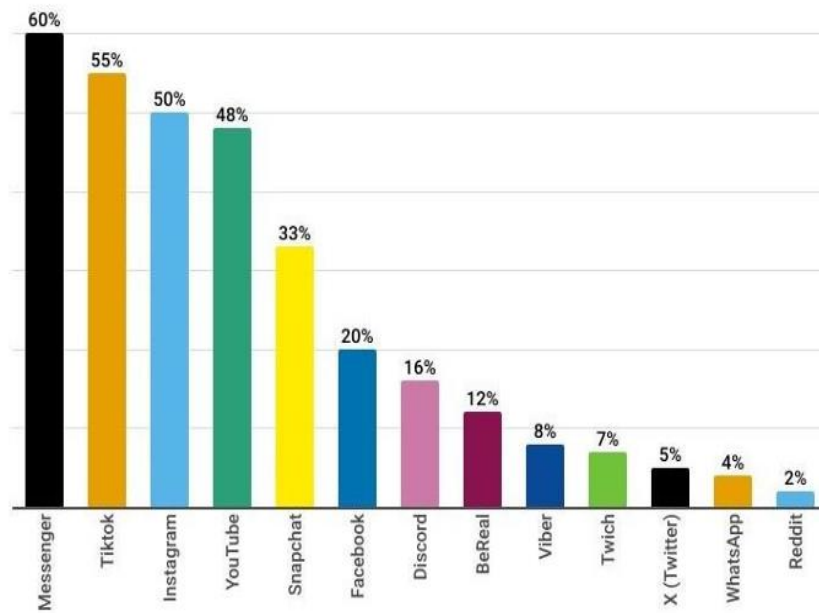


Figure 1
Most commonly used apps among 13-16 year olds (in Hungary) [23]

The research, conducted in spring 2024, examined the 13-16 age group and found that Messengers and TikTok are the most commonly used apps in this age group, which is typical for this demographic. It was found that the two most important motivations in this age group are communication/connectivity and wordplay [6]; [8]; [9]; [13]; [20]; [21]; [22]. Messenger satisfies the former motivation, while TikTok satisfies the latter [23]. Technological developments in sport, and communication in particular, have brought changes. Due to the development of digitalisation and the increase of time spent on the phone, there is a growing emphasis on the development and maintenance of mobile applications [7]; [9]; [12]; [14]; [17]; [18] [19]; [21]; [22]. The following are ways to help sports clubs communicate with and engage with their fans:

- consumers receive information in real time,
- provide a personalised user experience,
- Build strong relationships between companies and users [9]; [14]; [16].

Professional clubs abroad are no strangers to sports business mobile apps, as they have seen the benefits of using the app to help drive fan engagement. Building engagement is important because a stronger brand love can be identified in engaged fans, which also means a greater willingness to spend [4]; [15]; [17]; [22]. After all, the team has become part of the fan's identity [5]; [8]; [10]. Social media, and even more so mobile apps, go hand in hand with fan engagement, as highly engaged fans are more interested in team news and want to receive information in real time [5]; [8]; [11]; [14]; [15]; [20]; [22]. To succeed, a conscious, planned framework has been created, and communication through mobile apps is playing an increasing role [5]; [11]; [15]; [16]; [17]; [19]; [21]. Despite this, the development of mobile apps in the domestic sports scene is still in its infancy, with few sports teams claiming to have their mobile app [3]; [4]; [12]. In our country, social media is still the most used and used by sports clubs, with few activation activities [2]; [4]; [12]; [17]; [20]. It should also be pointed out that, in contrast to social media, the application is in the hands of the clubs, so there is no need to fear that they will report their Facebook or Instagram pages, or that the platform will be withdrawn from Europe, thus eliminating the social media page of the team. Several researchers agree, there are three types of media for a business, including a sports club [1]; [7]:

- Owned Media
 - Owned media refers to the channels owned by a company to communicate directly with its target audiences and to control and use their content, which is managed by the company [1]; [3]; [7]:
 - Webpage
 - Blog/Vlog
 - **Mobile app**
 - Paid Media
 - Paid media is content that a company pays for to reach its target audience [1]; [3]; [7].
- Earned Media

- In marketing, earned media is content that is created by third parties about a company or product.
 - Shares and likes on social media
 - PR-articles
 - etc... [1].

2 Research question/Hypotheses:

The main question of our research is: How effectively does a Hungarian sports club, Falco-Vulcano Energia KC Szombathely, use its mobile app?

Q1: Which news topics are the most interesting for the fans?

H1: The opening rate of news about the team posted from Falco's mobile app is higher than the opening rate of the match result.

Q2: Does the opening rate vary depending on whether the club is playing a home or away match?

H2: The opening rate of match result news posted from Falco's mobile app is higher for away matches than for home matches.

3 Method

From the research questions, it is clear that our main objective is to provide statistical data and literature to support how a mobile application developed by a sports club can be integrated and monetized in the life of Hungarian sports clubs. The examples from abroad show that the development of mobile applications is of great importance. We want to show how an app can be used to build a dedicated fan base for a sports team, which can help to increase business-based revenues in the short and long term.

Our research was structured in two parts. In the first period, we carried out a document analysis, the keywords of which were:

- mobile app,
- digitalisation,
- digital engagement
- sports marketing,
- fan engagement
- notifications.

In the second phase of the research, the primary data collection started at the six-time Hungarian basketball champion Falco-Vulcano Energia KC Szombathely. In the

course of the joint work, we started to analyse the data of the notifications after receiving the permission from the company Pressenger (developer of the Falco-Vulcano Energia KC Szombathely mobile app) and the club of Szombathely. The developer provided insight into the software they use, from which we obtained the statistical data. The data collection period was from 7 October 2024 to 26 March 2025, so we could measure the performance of the notifications sent during this period. The system allowed us to categorise the notifications sent out:

- Game Days notifications
 - GameDay!
 - The results of the quarters
 - We only measured the notifications of the final results
- Non-Game Days notifications
 - Opta Facts
 - More interesting statistics on the next opponent
 - Day before the match (1 or 2 times a week)
 - Weekly Schedule
 - The team shared news about the weekly schedule of the team (practices, travels, games, off-court events)
 - The start of the online ticket purchase
 - Big news
 - Injury report(s), new player signing (we could not plan it, that's why we did not measure it.)

4 Results

The app was available in both the Google Play Store and the App Store during the period under review. The Szombathely club's app was downloaded by a total of 1708 people. - Thanks to the Google Play Store's rating option, 24 people gave their opinion, giving the club's app an average rating of 4.4 stars. On the Apple App Store, 6 people gave their opinion with a rating of 4.7. The above results show that fans value the club's activities.

A total of 345 notifications were sent out during the period under review (07/10/2024 - 26/03/2025). Focusing on the 6 months, we can observe the 1-2 notifications per day from the club mentioned above. There were days when the club did not send sales notices due to holidays or league breaks. In terms of data, fans opened the "Weekly round" most often for information about the club, with an average of 15.18%, which is outstanding because an average opening rate (taking into account all industries and notifications) is 2.7%, compared to the 15% opening rate for the notifications sent out by the club. The reason is simple: the fans are curious about the team's weekly schedule, and the Szombathely club is communicating this information promptly. The other permanent notification above the 10% opening rate is the "Interesting Facts"

section, which was opened 10.39% of the time. It is also clear that fans use the app not only to get information. The club app is used to buy tickets and products, to get information, and, importantly for the club, to reinforce the club's identity through its visual design.

Looking at our hypothesis, it is clear that match-related news is not the most-read notification. **Our hypothesis 1:** *The opening rate of team-related news posted from Falco's mobile app is higher than the opening rate of match results.* - Confirmed. Figure 2 shows the difference.

Name	Android notifications	iPhone notifications	Openings on Android	Openings on iPhone	Opening Rate
Yes	130085	79959	7866	6519	6,85%
No	64008	45331	7406	5349	11,66%
Total amount	194093	125290	15272	11868	

Figure 2

Comparison of statistics on matchday and non-matchday notifications in Falco's mobile app

It can be seen that the opening rate of non-matchday understandings is almost double. This does not mean that the fans of the club in Szombathely are not interested in the result, but thanks to the graphical presentation, they received the necessary information (final result) without opening the notification, as illustrated in Figure 3.



Figure 3

The notification of the Final Result

The opening rate of matchday result notifications was 6.85% in the period under review, while the opening rate of non-matchday notifications was 11.66%. The difference can also be explained by the fact that the fans in Szombathely followed the matches live (on the spot or streamed), so for them, the mobile app did not add any value. In contrast, the non-matchday notifications provided fans with news and information that they would not have been able to find out at home, so the higher opening rate is understandable. It can be observed that nowadays it is important for

fans to feel as close to the club as possible and to have as much information as possible from the club outside match days. This result also shows that the notifications and news about the club to the supporters can be decisive. The club also facilitated this through the so-called Call To Action method. In the non-matchday notifications, Sombathely used asking or prompting phrases to increase the opening rate, as illustrated in Figure 4.



Figure 4
The use of the Call To Action

Our hypothesis 2, that the opening rate of match results posted from Falco's mobile app is higher for away matches than for home matches, **was confirmed**. The data is presented in Figure 5.

Name	Android notifications	iPhone notifications	Openings on Android	Openings on iPhone	Opening Rate
Home Games	76455	45756	4145	3564	6,31%
Away Games	53630	34203	3721	2955	7,60%
Total amount	130085	79959	7866	6519	

Figure 5
Comparison of the opening rate of match result notifications posted in Falco's mobile app for home and away matches.

Figure 5 clearly shows that away matches are viewed more often (7.60%) than home matches (6.31%). What could be the reason for this? Fewer fans can accompany the team on away trips, so fewer people see the live events compared to home matches. The team also publishes the results on social media, but fans can "only" see the quarterly results, not the full picture or who scored the points. The team can also deduce from the results here the size of the fan base that, if they cannot travel with the team, is interested in all the statistics. With this information, the club can also calculate the number of "so-called hardcore fans", which in the long run will help them to communicate with sponsors in a data-driven and conscious way.

Conclusion

The data and the trend shows that the time spent on screen time has already exceeded and will far exceed the time spent on social media. What does this mean for sports clubs? We need to move forward with digitalisation, but also keep an eye on trends and be aware that although social media is free, the platform does not belong to the teams, so they are exposed to the algorithms of Facebook, Instagram, TikTok, and their decisions. By contrast, developing and maintaining a mobile app is a business-based activity in the long term. What does it take to make a successful app?

One of the most important pillars for the success of the mobile app is to share information that is of interest to fans. It's also important to remember that, unlike social media, it's not worth fighting for 5-6 notifications a day here because it will be counterproductive. Experience at the Saturday club tells us that 1 or 2 a day is ideal (match days being the exception). Working together with the club and Pressenger, the goal is to increase the open rate of notifications by adding pictures and even interesting text to make them more exciting, with the aim being nothing less than to get more people to read the article.

The research also provided answers to the question of when and at what time of day it is worth sending the notification (it is important to note that this can only be taken for the measured period and those using the Falco app). We did not specify hours, but times of the day, and the result was that the opening rate of notifications sent in the afternoon was higher than the opening rate of notifications sent in the morning. This may be related to the measurement of the distribution of total daily screen time, and the result was that we use our smart devices most in the afternoon. Many people work in the morning and may therefore be less interested in the information in question, while in the afternoon, after work or when a little tired, people are more likely to pick up their phones during work.

With the help of the data obtained here and the graphical display of the notifications, it is a good opportunity for teams to market this interface to their sponsors.

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The Realities of Art Misconceptions in Ghana

(A study on misconceptions surrounding the study of the arts in senior high schools in Ghana and how a positive attitude towards the creative arts could enable sustainable living.)

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Abstract: Art is a way of life (Bauman, Z. 2013) that embodies freedom of self-belief and a way to make meaning of life. Art is an integral part of everyday life. Unfortunately, the regularity of these daily creative decisions has contributed to why many disregard art or do not perceive it as a respectable career. The creative arts industry has been a low-hanging fruit for many economies worldwide, with very little attention given to its vast potential, especially on the African continent. Failure to recognise and pursue art's social, cultural and economic value has been daunting on the African continent. The research has shown that studying art in senior high schools in Ghana is second to all other subjects. The warped perception (misconception) of people pursuing art programs, especially students in high school, has a long-term effect on the country's development. The research collected critical data from three (3) stakeholders (students, institutions and guardians) in the southern parts of Ghana (Accra and Cape Coast). The data analysis reveals the sources of this misconception and its effect. A significant ratio of art-based humiliation (misconception) suffered by art students comes from their peers (non-art students), followed by institutions (system and structures) and guardians. The thesis revealed that educational reforms and deliberate exposure of art knowledge to the research stakeholders could help build a perfect synergy of positive perception of arts, leading to a robust creative economy in Africa.

Keywords: Art Misconceptions, creative economy

1 Literature review

There are two significant groups of intelligence: intellectual (left-brained) and emotional (right-brained), which constitute the learning process of every human being on earth. Pursuing art requires cognitive and top performance from both the left and right brains. This statement means the study of art is for intelligent students, contrary to what most people perceive (Goleman, 2006). Some scholars noted that art education merits a significant part in the heart of the education curriculum because of its numerous benefits, mainly in reasoning and critical thinking.

Creativity in African children is overly controlled, meaning parents constantly tell their children what to do and how to do it. There is little room for children to follow their interests or find their own paths. "These controls leave children less confident about their originality, and following your heart is a waste of time (Ntim-Ofosu, 2018). If one asked Ghanaian children what career to choose when they grow up, most would mention professions like law, medicine, and engineering rather than art-related jobs.

The study and pursuit of art are not strongly encouraged in several communities in Ghana. It is often viewed as a non-professional pursuit, associated with individuals perceived as less intelligent or who have failed in life. This stigma is particularly prevalent in senior high schools, where students studying the arts frequently face humiliation (Agyare & Atiase, 2022).

These negative perceptions are classified as "art misconceptions." Any statements or actions that shame or humiliate individuals who choose to pursue the arts hinder the social, cultural, and economic transformation of our communities.

This study aims to understand the sources and long-term effects of art misconceptions in Ghana's senior high schools and propose ways to foster a community that values creativity.

2 Methodology

The debates and discourses on art misconceptions and the value of art have been carried out by researchers, policymakers, and international organisations around the world; it is crucial not to pick and adopt any research approaches, strategies, and models for the study of the impact of the creative misconception on African creative economy keeping in mind that any viable empirical assessment of the relevance of institutions, society and the senior high students needed to be approached and observed in its uniqueness, incited the study to adopt quantitative and qualitative research strategies.

Quantitative Strategy: The quantitative approach helped to form the hypothesis and then use deductive reasoning by forecasting how the data should look if the hypothesis is true after collecting and analysing it to confirm or reject it. Researchers who use this method aim to create a general understanding of the behaviour and other phenomena of the students and guardians.

Qualitative Strategy: This strategy allows researchers to approach the field inductively by generating new insights, theories and hypotheses based on emerging data collected from observations and interviews. Another benefit is the iterative nature

of this approach, which allows for understanding a phenomenon from different perspectives.

The research was conducted in Accra, Ghana, from June to July 2022. Every respondent gave consent to the use of the information. The research targeted three groups, and each group had a different survey approach.

Students: The first group was senior high school students aged thirteen (13) to nineteen (19) years in the Greater Accra region in Ghana. The criteria for choosing the schools were based on the background that the students came from, all sixteen (16) regions of Ghana, with diverse socio-economic backgrounds, which makes a good representative of SHS students in Ghana. The hardcopy forms were circulated to students during a special event - an inter-school sports competition. The event was an annual regional sports event that involved over thirty (30) schools participating from the Greater Accra region. The respondents came from seventeen (17) schools (Public and Private schools). Three hundred eighty-six (386) participants filled out the printed survey form.

Guardian: The second group were parents with children actively schooling in senior high schools, who were the target for the survey. British English is the official language of Ghana; hence, the survey content was in English. The responses were slow at the beginning. Coordinating teachers had to call several times to send reminders to parents to fill. The researchers had to make direct calls to get submissions. At the end of the period, we recorded one hundred and thirteen (113) respondents.

Institution: The view of educational institutions' authorities was relevant in understanding the art misconceptions. Nine (9) interview questions were self-administered to gather the thoughts. The interview opened up the discussion for deeper understanding. The interviews were held and recorded via Zoom. The time allocated for each interview was 45 minutes. Recorded audio was transcribed.

Interviewees	Institution	Description
Mr James Nii Allah	Achimota Secondary School	Painter and teacher - Picture making, Graphic Design, General Knowledge in Art and other support.
Desmond Edofofani	Mepe St. Kizito Senior High/Technical School	A sculpture and a teacher: General Knowledge in Arts and Sculpture.
Isaac Ebowah	Archbishop Porter Girls Senior High School	Painter and teacher in Ceramics and General Knowledge in Arts

Table 1
Overview of Interviewee

Hypothesis

Hypothesis 1: Students studying art in senior high schools suffer some form of humiliation from their peers, school authorities, and society, which has a significant negative impact on the creative economy in Ghana.

Hypothesis 2: The researcher also states that most guardians do not want their children to study or pursue an art career.

3 Findings

This chapter presents evidence indicating that rooted misconceptions exist in the study of art, which has social, cultural, and economic impacts on Ghana. Through the data analysis methods outlined in the previous chapter, the researcher highlights the origins of these negative behaviours, from students to guardians and the national systems designed to shape the new generation.

3.1 Students' understanding of the misconceptions in art.

Out of the three hundred fifty-five (355) responses, 58% were second-year students, 32.7% were third-year students, and the remaining were first and other years based on diverse curricula. 56.9% of the respondents were non-art students; the remaining studied art or art-related subjects. Also, about 15% of the student respondents were from private/international schools, and a more significant proportion of the respondents were from public schools.

This creative interest was challenged when I asked the art students (247 respondents) if they had suffered humiliation for wanting to do art. The majority said yes by choosing the group that caused the most humiliation.

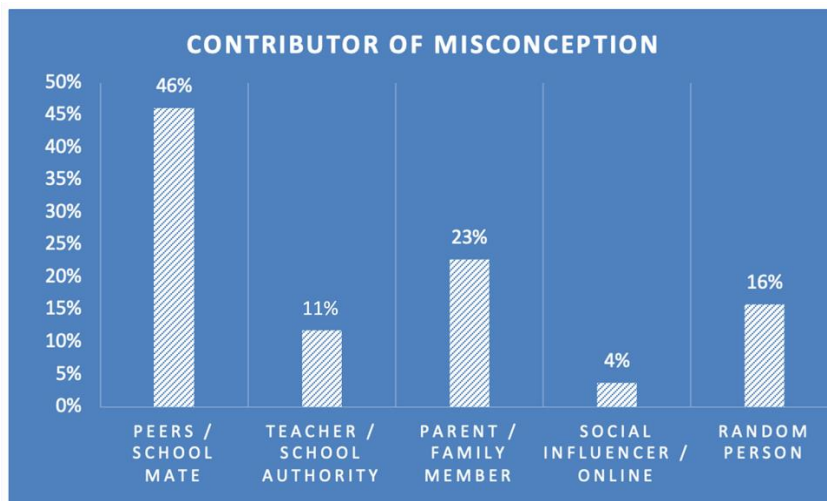


Figure 1
Contributors to the Humiliation of Students

First, Readers should note that the humiliations are the art misconceptions children encounter when they want to or are living their creative abilities, whether it is a hobby, studying art or having an interest in an art career. The result shows sources of art misconceptions about art in public senior high schools in Ghana. The data in Figure 1 shows that art and non-art students were the primary source of humiliators (**peer group at 46%**), followed by parents/family/ random people in the society (**social group at 43%**), and finally, teachers/school authorities (**institution group at 11%**). This study classified negative influences from social media platforms as part of the social group.

The analysis emphasises that peer influence is essential during character-building in young adults. Students listen and seek validation from their fellow students, and these conversations and challenges are primarily not discussed with their guardians. The humiliation comes from both art and non-art students. Their ignorance of the possibilities of art and the negative influences of society has shaped their thoughts and has made them naysayers or non-believers. If an art student does not love the course because he or she does not see a future, the reactions and behaviours towards art and the training process will be a bad experience.

Non-art students make negative utterances toward fellow students interested in art, which is heartbreaking. But it hurts more when art students themselves do not believe, hence, say negative things about what they study or about art. It makes them feel not so special and a bit on the wrong path. Some keywords/phrases were collected from the sample verbal utterance during the survey. Statements like “*waste of time, not a proper job, useless, misfit, not respected, and no future*” illustrate the heart-breaking moments for students offering art. This gets into the subconscious, becoming a daily struggle to prove the naysayers wrong or succumb to their defeat. This has become an everyday battle for art students with little or no knowledge of what they could do with the art. It is not surprising to notice that the majority of the respondents are indifferent or agree that these negative attitudes have a negative impact on the studies of art students (Figure 2).

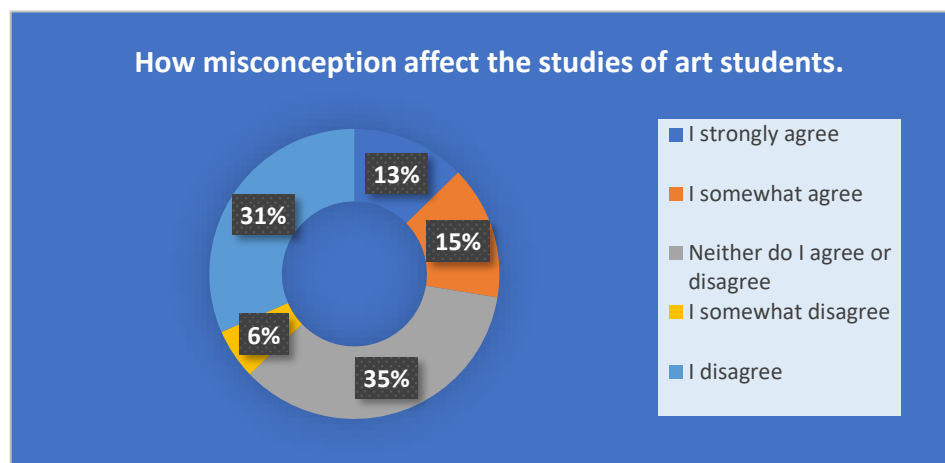


Figure 2
How Misconception Affects the Studies of Art Students

On the contrary, over 70% of the student respondents agreed that art could be a respectable career and would play their role in convincing everyone if they had the opportunity. They believe art could change their society and the world. This is a good

indicator, and if the authorities implement a system that provides the proper knowledge and infrastructure in art, there would be a positive yield. But that is not the case in the public school. It is worse when you believe something has great cultural, social and economic relevance to the country but still disregard it. Maybe this understanding is on a shallow level, and they are not knowledgeable enough.

3.2 Findings from guardians (Social group)

As indicated in the above sub-chapter (figure 1), parents or family, social influences, and online communities are the second group of humiliators. This is because parents and the community have a significant influence on shaping the minds and behaviours of young adults. One hundred and thirteen guardians were involved in a survey to appreciate their stand on the research topic. The majority, 76.1%, were between thirty-one (31) and fifty (50) years old. 36.3% have three (3) children, 30.1% have two (2) children, 21.1% have a child, and the rest have more than three children. The number of children in school is almost equivalent to the percentage split mentioned above.

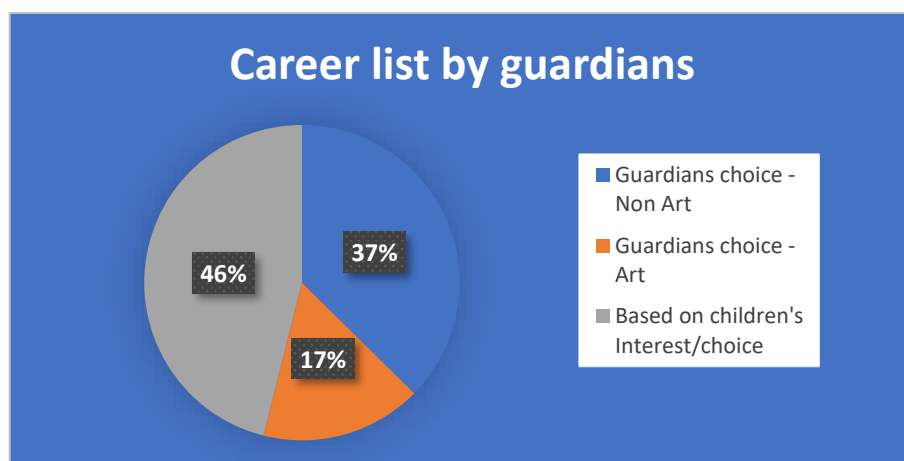


Figure 3
Analysis of career choice by Guardians

Guardians were asked if they had a career they wished their children would pursue, and my analysis of their response was unexpected. There was a tall list of careers that was categorised into three groups. Non-art career choice by guardians, art career choice by guardians, and career choice based on the child's interest. 17% of the respondents wished their children would pursue an art career. 46% of the respondents acknowledge that the interest of their children is an essential factor in choosing a career path. Keywords like “depends”, “interest”, “their strength”, and “their choice” are good

indicators that the middle class and upper class seek to involve their children in career decisions. I also noticed that many careers listed were not art-related. This shows that guardians are becoming more open in the new world where no more dominating career(s) can guarantee sustainable living.

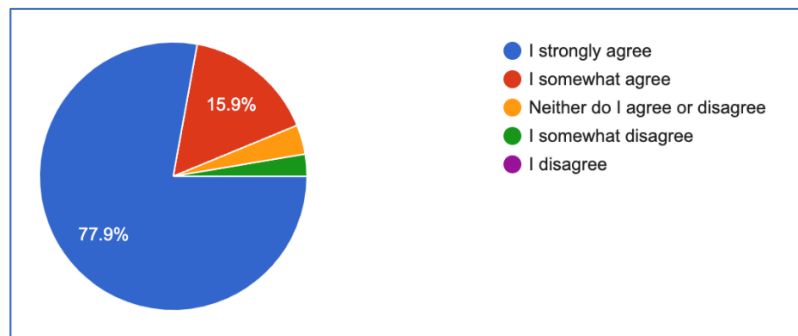


Figure 4
Guardian's response on the belief that a child can have a successful career in art

Guardians strongly believe their children could have a successful art career if they choose. The data proved that more than 77.9% of the respondents are willing to support it even though guardians are the second contributors to the creative misconception. To uncover their true thoughts and perception of art, a linear correlation was developed to find any relation between guardians' support for their children's creative course and where they would pursue an art course if they had a second chance to choose a course as a child. This analysis intends to test their love and commitment to artistic endeavours. The linear is inclined, which is a positive correlation.

3.3 Comparative Analysis of Art Misconceptions in students and guardians

A spider diagram shows a comparative analysis of the misconceptions between the guardians and students. I paired questions from these two groups that were strongly linked with the core areas, providing stronger evidence of the misconceptions. The responses were then coded into a unified rating from zero(0), the lowest rate, to ten(10), the highest rating.

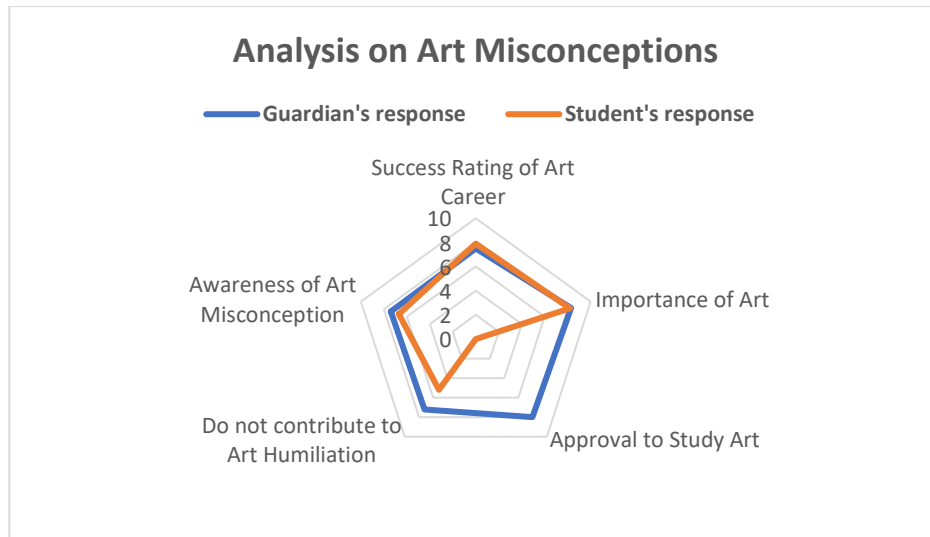


Figure 5
Comparative Analysis of Art Misconceptions

The grouped questions:

- Approval to Study Art: Do parents and children think they would approve and support each other in a decision to study art?
- Do Not Contribute to Art Humiliation: Has any group said or acted negatively towards art and the study of art?
- Awareness of art misconception: Do you think art is for failures?
- Success Rating of Art Career: Do the two groups think anyone can have a respectable and successful career in art?
- Importance of Art: Is art relevant in our social, cultural and economic life as individuals or as a country?

The data reveals that both groups understand that anyone can have a successful career in the arts. They are also aware of the misconception surrounding the study and art practice. Still, you can also see the contrast between the results in their contribution to the humiliation. Students contribute more to the humiliation than parents. As stated above, peer humiliation tops the chat. This could also result in parents loving and supporting their children irrespective of any disagreement on the course they want to pursue. This shows that the guardians in this study put the interests of their children first when it comes to their academic and career paths.

One outstanding contrast in the spider diagram is the approval to study art. The data show that children do not think their guardians would want them to study art in senior high school. This may result from stereotypes and the possibility of humiliation if they

choose the art course. Still, surprisingly, the data shows that guardians are more likely to approve of their choice. I also want to highlight that the guardians in this study would be classified in the middle-income range (living standard measure). If the research was conducted in a rural location with lower-income status, maybe guardians would not consider art an option.

3.2 Findings from Institutions

This chapter presents the qualitative results from the perspective of selected authorities representing three schools in three regions. The strategic selection ensured the body of work captured the reality in schools in rural and urban communities. Achimota School represents the urban schools (Greater Accra Region), Mepe St. Kizito Senior High/Technical School represents the rural school (Ada community), and Archbishop Porter Girls Senior High School (Western Region) is a blend of the two.

The teachers interviewed were from the visual arts department of their respective schools. The intention is to get a proper perspective of what happens in the department and the management level of their schools. All the interviewers taught art subjects, and they have been involved in administration processes like the selection and admission of students and the academic and operational management of their schools. The endeavour brings them into contact with parents quite often. Thankfully, all of them practise art as a second career. The above-stated roles make them the ideal respondents to share their opinions and thoughts on the misconception that they still suffer as teachers and artists.

3.2.1 How the admission process downplays the art subjects

The Ghana Education Service (GES) is solely responsible for validating and placing junior high graduates into senior high schools. The process allows students, under the supervision of their parents, to choose their preferred courses and schools before the placement period. Isaac indicated that it had become a trend for graduates/guardians to choose an art course as a preferred course to be admitted into their preferred school, so they can change their course to a non-art course. In other words, choosing an art course becomes a way to get into the school, so they can change their course when admission is completed. Most of the students in the art department got there as their last option, as they did not pass the other non-art courses (James). There is no cut-off grade for admitting a student into the art department, unlike other courses. The art course has become second to every other course, hurting the very few who chose art as their preferred course.

...Sometimes you are lucky you can get about 5% who genuinely want to do the program, who came with single grades and want to do the subject; it is not much, but how can I say... the chunk overrides the good students, and it disturbs the class as well since most of the students are not academically strong, they how do I say... they muffle the 5% who are very serious. (Isaac)

The situation is worse in rural schools, where GES usually places the worst-performing graduates. Desmond lamented that the teachers in rural schools like his had to work twice as hard as those in urban communities to calm the chaos in the department.

3.2.2 How does the lack of infrastructure contribute to the narrative?

GES is the government agency responsible for developing infrastructure in public schools. Taxpayers contribute a 2.5% levy to the Ghana Education Trust Fund (GETFUND). This revenue is used to manage the education ministry, including the construction of school infrastructure. Among the three schools in question, all structural improvements were allocated to other departments except for the art departments. Under the Free Senior High Education policy, the government chose to subsidise tuition, which included learning materials, but tools and equipment for developing art skills were unavailable.

The GES is more interested in the sciences than in the arts, so if you are given somebody a question to fire their works, or throw their works on the potter's wheel, then you also have to make arrangements or find the means necessary to ensure that every school in Ghana, offering visual Arts, is having a good studio, a working kiln, a working porters wheel, a light room, and lightboxes. So it is either you encourage the schools to do them on their own, or you find ways and means to fund such infrastructural developments in schools, because I have never heard the GES saying, let's do this for the visual Arts students (Desmond)

There are severe disparities, but the non-existence of proper art studios in senior high schools explains why studying art in Ghana is considered a waste of time. To develop skills that meet the global market, the studio must be equipped with the latest technology to build the right skills.

3.2.3 Teaching and the art syllabus

GES trains most of the teachers at the Teachers Training College. The teacher focuses on the area of specialisation according to the syllabus. Art is a unique subject that requires teachers with special skills. Teaching art requires the theory and the practical aspect, so it sometimes becomes challenging to find a teacher who easily fits the department. In most situations, the school designs an elective subject based on the

teacher's skill. Here is a case where sometimes teachers are forced to teach a subject with limited skill knowledge (James). Art is passion-driven; if you lack the passion, you cannot inspire and impact your students. Also, teachers who offer mandatory core subjects like core mathematics, social studies, and core science must be trained in art or have some art background to differentiate the approach when teaching art students. Art is one of the most challenging subjects, and teachers from the training college would need to update their methods to perform rather than engage them with the perception that art students are not brilliant.

I used to teach prehistoric Arts, African Arts, and Renaissance Art, and you would be teaching it verbally and talking about the Bambara of Mali. The Minerals of Sierra Leone, Da-Vinci, and Michael Angelo's David and these kids are just looking at you like they have seen a ghost. Still, now we project the works for them, we talk about the artists, they see their works, oh so this is what Monalisa is, so this is what the creation of Art is, oh so this is what Chiwara Mask looks like, and you can tell that the students pick up a huge lot of knowledge. (James)

There were some concerns with the more than thirty-year-old art syllabus. James also agrees that the content of the general knowledge in art has a history of the very old artists. There are recently iconic artists like Amoako Boafo, whom students can read about, be inspired by, and resonate with. The methods and the approach for many of the experimental processes required for final exams are obsolete. These operational requirements need to be improved to prepare students for the job market. If not, we will keep increasing the gap between what is being learned and the realities of the job market. These gaps contribute to the misconceptions.

3.2.4 Industry Collaboration

More industry collaboration needs to be conducted at the senior high level, as highlighted by Desmond. Some talented students have the passion and seek ways to turn this into a fortune. In urban communities, the school authorities sometimes organise or get invited to some art-related events or competitions. Corporate bodies, brands, and social workers sometimes engage them on a project basis. A school like Achimota got its art school renovated through Artlife Matters and some old students. Archbishop Porter's Girls' Senior High School also got its art department refurbished by its alumni. Mepe St Kizito Senior High still struggles to call a space their Art studio because it is located in a rural community. Schools in such locations barely attract opportunities that would inspire and spark the hope that they, too, would be able to have a sustainable career through the arts.

Conclusion

The study explored how students, guardians, and institutions understand the value of art and how the Ghana Education Service systems and structure significantly contribute to individuals' and society's lack of ability to achieve the vast potential of African creative potential. Critical analysis of the data gathered from structured qualitative questionnaires and interviews revealed the following causes.

Art and non-art students in senior high are not exposed to art in a way that would allow them to value art and have a respectable and sustainable career. Both students and guardians agree that the pursuit of art is very relevant in character-building in children or teenagers. Hence, the study or engagement with art should not be limited to art departments, but every student should have a lifetime opportunity to express themselves through an artistic experience.

In the study analysis, it was understood that students do not think their parents would allow them to pursue art, and most parents also agreed that they would allow their kids to pursue art. This contradictory response indicates that the perception of parents and society may be changing.

Data shows that parents are much more interested in what their children want than in what they desire for their children when it comes to selecting a course or career path. However, few of them would fully support a pursuit in the arts. The statistics indicate that respondents have a limited understanding of the opportunities within the art sector, and that the level of acceptance will improve if they are exposed to and fully comprehend the vast potential of the creative industry.

Ghana is a beautiful, peaceful country with a diverse culture and a great history. Every expatriate feels welcome once they step on Ghanaian soil, and this is exhibited through art and culture. This uniqueness should reflect in the way we see and understand art. The misconception in this study is clearly a behavioural concern that can only be resolved with time. The following pointers may help reshape our thoughts towards a more deserving future with art.

Educational Reforms

Ghana Education Service (GES) needs to review and adjust the process of recruiting teachers for art departments in senior high schools. Strategic thoughts would go into training teachers who understand the theory, practical and mentoring of art students. The syllabus would have to be reviewed to reflect recent times.

The advent of digital technology is fast-changing the way art is applied in various sectors of our lives. However, the current school curriculum for the art department still uses old ways and outdated learning knowledge. Most senior high schools do not have

a dedicated computer lab for digital lessons. Students still practice with traditional methods, forgetting that the real world operates differently.

As mentioned earlier, the art department's admission process has no cut-off grade. Students who fail to get their preferred subject in non-art course areas are put in the art department as a last resort. My research highlighted that about 5% of the current art student in the research schools chose art as their preferred course. This means the departments are filled with confused students who are still trying to make sense of the art course. GES should have a safety net to admit many more students with art interests, or should find a way to improve the interest in students pursuing art in senior high schools in Ghana.

Industry Exposure

Ghana's creative art and culture industry has slow growth, but there are a lot of individual achievements and global recognition. Ghana has become a spotlight for the international contemporary art scene with Amoako Boafo, Kwasi Botchwey, and many more, selling at record prices in auction houses, museums and private collections. There is a gap between what is taught in the senior high school and how things work in the creative art space. And this gap can only be closed if there is constant interaction or collaboration between art students through the schools and the industry players. This will give the students great exposure and inspire them as they see and interact with people they wish to be when they grow. Knowing what you can do with your studies will give students a new purpose and confidence to defend themselves when they encounter misconceptions from naysayers.

Parents and society must frequently dialogue and interact with the art industry to understand the dynamics of art and how it can help develop the country's cultural, social, and economic areas. Art institutions and industry stakeholders must have an agenda to grow a robust industry that involves the young and upcoming, the practising artist, or entities with a national interest.

Government Interventions

The government of Ghana believes in the potential of the creative art and culture industry. In 2020, the parliament passed the Creative Arts Bill, intending to establish a government agency to protect, guide and manage a vibrant creative economy. The country needs initiatives, policies, systems, and structures that protect and encourage young children to have a sustainable career through art.

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The Intersection of Personal ICT Use and Company Risk Exposure

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Abstract: Profit-oriented and non-profit organizations face increasingly complex security challenges due to the growing use of shared devices for both professional and personal purposes. The line between the public and private domains is becoming progressively blurred, particularly in the digital realm: as users access a wider array of online services, they become more vulnerable to various forms of cybercrime, notably identity theft. Current research is exploring how the rising frequency of cybercrime impacts national security as a whole. To complement these studies, this paper aims to develop an integrated risk map for both profit-oriented and non-profit organizations. This map will be informed by data on information security incidents sourced from national and international publications. Furthermore, the paper will examine the role of information security management systems in mitigating these risks. The central research question, 'How can existing information security standards effectively address emerging threats?' will be addressed in this analysis.

Keywords: ISMS, cybersecurity

1 Introduction

This study explores the potential risks to corporate IT infrastructure when ICT resources owned and operated by employees are incorporated into an organization's daily operations. It presumes the existence of the two widely recognized categories of IT crimes, as defined in [1]:

Cyber-dependent crimes are criminal activities that can only be executed with the use of information and communication technologies (ICT), such as computers, networks, or other digital tools. These crimes are distinct from traditional criminal acts in that their commission is inherently tied to the technological environment. The motivations behind cyber-dependent crimes can be varied and multifaceted. In many cases, financial gain is a primary driving factor, as cybercriminals exploit digital platforms to generate illicit profits, whether through fraud, theft, or other illicit financial activities. Additionally, some criminals may aim to disrupt or damage the operation of computer systems or networks, causing widespread operational failures that can

severely affect both individuals and organizations. Another significant motivation is the theft of personal data, which is often used for fraudulent activities, including identity theft and financial exploitation. The methods employed to carry out these crimes are diverse and increasingly sophisticated. One common approach is the deployment of viruses and other forms of malicious software, which can infiltrate systems and cause extensive harm, ranging from data loss to unauthorized access to sensitive information. In many cases, cybercriminals use malware to gain control over systems, often leaving the victims unaware of the breach until it is too late. Another prevalent technique is hacking, where attackers exploit vulnerabilities in computer systems or networks to gain unauthorized access to private data or disrupt normal operations. In addition, denial-of-service (DDoS) attacks are a widespread method of cybercriminals, wherein internet servers are overloaded with massive amounts of traffic, effectively rendering websites or entire networks inaccessible. This type of attack is particularly disruptive for businesses and organizations that rely on their online presence for daily operations, as it can lead to significant downtime and financial losses. Cyber-dependent crimes are intrinsically linked to the digital world, and as technology advances, the frequency and complexity of these crimes continue to increase. The rise of digital platforms, combined with the growing interconnection of networks, has created new opportunities for cybercriminals to exploit vulnerabilities in cyberspace. As these crimes become more sophisticated, they pose ever-greater challenges to cybersecurity professionals and organizations seeking to protect their digital assets and sensitive information. The evolving nature of these threats requires continuous adaptation of security measures and strategies to mitigate risks and respond to new and emerging cyber threats effectively [1-3].

Cyber-enabled crimes refer to criminal activities that use information and communication technology (ICT) to facilitate or enhance traditional criminal acts. These crimes, which include online fraud, harassment, and intimidation, are distinct from cyber-dependent crimes in that they can still be committed without the use of ICT. However, the application of digital tools and technologies significantly increases the scale and reach of these crimes. The primary motivation behind cyber-enabled crimes often revolves around financial gain, with cybercriminals exploiting the digital environment to carry out fraudulent activities. Typical examples of these crimes include phishing, where fraudsters send deceptive emails pretending to be from legitimate sources to steal sensitive information, large-scale fraud schemes, theft, and sexual offenses against children. In the context of profit-oriented environments, economic crimes such as fraud are particularly prevalent. These types of crimes, made more efficient through the use of ICT, often have a significant financial impact on individuals, companies, and organizations. **Cyber-enabled data theft** is a prominent issue in this regard, as cybercriminals seek to steal personal, financial, or corporate information to commit fraud. The data targeted by cybercriminals is highly valuable and can include personal information such as names, bank details, and National Insurance numbers, as well as corporate data like company accounts, client databases, and intellectual property such as new products or innovations. The theft of such data can lead to significant financial losses and reputational damage for both individuals

and organizations. **Cyber-enabled crimes** are, in essence, hybrid crimes, arising from the integration of traditional criminal behavior and networked technologies. According to Wall (2007), these crimes have become increasingly prominent as a result of the rapid growth of networked technologies, which provide criminals with new opportunities to commit offenses on a larger scale and across broader geographical areas. The ability to access individuals in remote locations and the anonymity provided by the internet have significantly expanded the potential for such crimes. While these crimes could still be carried out in the absence of networked technologies, the opportunities for large-scale attacks, as well as the ease of reaching potential victims, would be greatly reduced (Levi et al., 2015). Examples of cyber-enabled crimes include phishing, identity theft, large-scale fraud, and the distribution of illegal content, such as online pornography. These crimes illustrate the growing intersection of traditional criminal behaviors and the evolving capabilities of digital technology, making them increasingly difficult to prevent and prosecute. [2-4]

Even within the context of traditional employment, where work is performed at the workplace during standard working hours, organizations must consider two primary types of potential risks, partly driven by limited rationality. The first involves the employee's own fault, such as the deliberate commission of an illegal act (e.g., internal fraud), while the second pertains to situations where the employee becomes a victim of external manipulation, such as social engineering. In what was previously referred to as "classic" employment, employees represent one of the most vulnerable points in the organizational security framework. In this context, employees utilize assets that belong to the organization—specifically, information and communication technologies (ICT) embedded in the organization's infrastructure. These assets are legally authorized and are typically under the control of designated personnel.

Today, this issue has become a central topic in discussions surrounding information security and human resources management. A pressing concern is the fact that IT-related attacks often serve as the precursor to further vulnerabilities within an organization's systems [5]. Focusing disproportionately on social engineering attacks tends to divert attention, thereby underestimating other associated risks.

Recent studies indicate that young professionals entering the workforce today—partly as a result of changes brought about by the global COVID-19 pandemic—possess significantly more advanced user knowledge compared to previous generations. Their use of ICT tools has become substantially more pervasive, further amplifying the challenges faced by organizations [6]. (This process was already identifiable and demonstrable well before the outbreak of the pandemic, but these trends have been significantly amplified and made irreversible by the global health challenge [7-8].) This situation can be mitigated by equipping the ICT infrastructure with a monitoring system capable of overseeing processes and transactions, enabling proactive defense mechanisms. However, organizations also face heightened risks from adopting Bring Your Own Device (BYOD) policies, where personal devices owned by employees are used for business purposes. This practice limits the organization's previously legitimate control rights over its assets, both legally (due to the lack of ownership) and

practically (since full access rights rest primarily with the users) [9]. Consequently, the risk exposure to the organization is significantly increased.

2 Problem statement: ISMS , BYOD, teleworking

Currently, ISMS (based on ISO 27001 or other standards) follow the widely recognized PDCA model- This iterative process begins with the "P" phase, where the ISMS is designed within the context of company policy, ensuring alignment with other organizational policies and identifying the necessary objects, processes, and procedures for continuous risk management. In the "D" phase, the operational aspect of the information security framework is implemented, which had been previously designed and integrated into the organization (e.g., creating regulations). The "C" phase involves evaluating the performance of the process, considering ISMS guidelines, objectives, and practical experience, followed by reporting activities. The results from this evaluation inform the final "A" phase, during which corrective actions are implemented to enhance the system [10].

Risk assessment is a key component of corporate security, as IT security is an integral part of operational risk management. This implies that both intentional harm and force majeure, along with human errors and technical/engineering failures, must be addressed. A homogeneous approach to risk management must be established to handle these diverse risks efficiently [10-11].

In the context of BYOD (Bring Your Own Device) tools, these are devices, typically smart tools, that are owned by the employee. These devices can be integrated into the company's information system in various ways. For example, they can be synchronized with company directories and calendars via an IMAP server, or files can be linked with widely used services such as Dropbox. Additionally, several enterprise management systems offer interfaces that are optimized for use with these smart devices [12].

High-latency incidents often correlate with information security breaches. A study by Crowd Research Partners (2016) surveyed 800 respondents and provided the following alarming results:

- 39% of respondents confirmed that malware had been downloaded at some point. However, 35% were uncertain about whether such an event had occurred.
- 24% confirmed that their BYOD device had been connected to an untrusted Wi-Fi network at some point, while 48% were uncertain.
- 21% acknowledged their BYOD device's involvement in a previous incident, with 37% unsure whether such an event had taken place.

My qualitative research focuses on how businesses can respond to global challenges and adapt to emerging trends in the digital age [11]. Specifically, it examines how companies are equipped to address the unique challenges posed by Bring Your Own Device (BYOD) policies. The research explores the strategies businesses can implement to effectively mitigate the security risks associated with BYOD while maintaining operational efficiency.

3 Qualitative analysis

After examining the Bring Your Own Device (BYOD) phenomenon and the advantages it brings, it is crucial to identify why these tools are often considered vulnerable. The risks associated with BYOD devices can be categorized into several types [14]: One of the primary concerns is physical risks, such as the device being stolen or the owner losing it. Another significant issue arises when a mobile device becomes damaged, rendering it unusable. Unauthorized access is also a critical concern, especially when a device is left unattended and accessed by a third party. Moreover, there are risks related to data logging through the mobile device, which could allow malicious actors to gain control over it via a data connection. In these cases, there are several potential outcomes:

- Data loss can occur if important information is deleted.
- Data loss can also occur while giving the attacker access to stored data.
- Data modification may happen either directly on the device or, in cases where a client is installed, on the company server, which might record unintended changes.

The installation and distribution of malicious programs within the company's infrastructure is another key risk, as is the potential for unauthorized SMS and MMS messages to be sent, contradicting the owner's intentions. Additionally, applications installed from trusted sources may still contain bugs that put security at risk.

In some cases, users may install applications that inadvertently cause harm, either directly or indirectly. Finally, misuse by attackers can occur both logically and physically, by using the mobile phone to exploit services that the user is automatically logged into, often bypassing the need for further authentication.

In the earlier sections of this study, I analyzed how the integration of external elements, such as ICT devices and remote workers, increases the vulnerability of corporate infrastructures compared to previous setups. Due to the lack of primary data, I draw conclusions based on quantitative analysis. Specifically, I evaluate the ISO 27001 standards in the context of BYOD devices and teleworking, while also considering additional factors that can enhance corporate security.

However, these ISMS systems have a fundamental weakness: the integration of IT infrastructures into the corporate environment, which significantly impacts corporate security. It remains questionable whether the scope of corporate standards applies effectively or whether compliance can even be enforced. Since these IT tools are not owned by the company, the ability to control them is inherently limited. Information security standards often implicitly assume that a company's tangible and intangible assets are fully under its control, but this assumption does not hold when external elements are involved [10].

Moreover, the traditional ISMS framework is increasingly inadequate because enforcing information security rules becomes substantially more difficult when those involved are not in close geographical proximity. In such cases, other cultural mechanisms may be required to maintain security standards [16-17]. highlights that the tools and institutions linked to the "visible" aspects of security tend to adopt a retrospective approach, while the development of values and attitudes is continuously evolving as part of the broader progression of information security practices.

If the illusion of security in collaboration with teleworkers can be dispelled, it becomes possible to raise security awareness through effective education and training programs (such as e-learning). Focusing on the real risks, such as "identity theft," serves as a powerful motivational tool. The risks discussed in this study are not only a threat to specific organizations but can also lead to substantial personal damage. A security-conscious attitude enables individuals to not only defend against known threats but also to develop skills for handling unexpected and unusual incidents, potentially raising awareness of malicious intent and better equipping individuals to address unforeseen situations effectively [15, 17].

Conclusions

This study focuses on the challenges organizations face when the logical components of their information infrastructure (such as BYOD tools) and both physical and logical tools are situated outside the company's control. These were considered "simpler cases," yet even in these relatively straightforward instances, each study revealed disturbing data.

Considering current employment trends, there is a theoretical need to develop a risk assessment model that identifies vulnerabilities and potential risk events that pose threats to organizations, but for which defenses are either not feasible or only partially effective.

Furthermore, it remains unexplored to what extent an organization might be at risk if an employee, whether a regular or teleworking staff member, were responsible for a complex IT crime such as identity theft. A survey is necessary to evaluate how widely these incidents affect organizations, examining how known cases reflect the severity of the impact on the respective employer. Additionally, individual attack profiles could be identified by analyzing case studies on specific incidents.

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IT Vulnerability Analysis of Industrial Network and Robotic Systems - Cybersecurity Challenges and Protection Strategies in Industrial IT Systems

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Abstract: In recent years, the convergence of industrial automation and information technology has significantly increased the complexity and vulnerability of industrial control systems (ICS). This study provides a comprehensive analysis of the cybersecurity vulnerabilities inherent in industrial IT elements, with a particular focus on network infrastructure and robotic systems. Through real-world case studies and technical assessments, the paper identifies key threat vectors, including remote access misconfigurations, outdated firmware, unencrypted protocols, and social engineering attacks. It further explores systematic methods of vulnerability assessment, such as passive and active network analysis, physical and logical security audits, and automated vulnerability scanning tools. The study also emphasizes the role of international standards and regulations—such as IEC 62443, ISO/IEC 27001, and the NIS2 Directive—in strengthening industrial cybersecurity. Additionally, it presents effective defensive strategies, including network segmentation, multi-factor authentication, SIEM integration, and the application of ITIL-based governance frameworks. The findings highlight the urgent need for continuous monitoring, targeted training, and proactive security architecture to ensure the resilience and operational continuity of industrial environments in the face of evolving cyber threats.

Keywords: Industrial Cybersecurity; Vulnerability Assessment; SCADA and ICS Security; Robot Systems; Critical Infrastructure Protection

1 Introduction

Along with the digitalisation of industrial systems[1], vulnerabilities in industrial IT infrastructure[2] have increased dramatically. Automated production lines[3], robotics systems[4], and SCADA-based control systems[5] are being increasingly closely integrated into classic IT and network environments[6], bringing with them new types of threats[7]. The widening of attack surfaces[8] –such as remote access[9], inadequately updated firmware[10], social engineering methods[11], and unencrypted industrial protocols[12]– makes these critical systems particularly vulnerable.

Industrial cyber security[13] is therefore not only an IT task, but also a strategic issue that affects the continuity of production[14], personal safety[15] and economic competitiveness[16]. The logical security audit[17] and related defense strategies[18] are not in themselves, but international standards (ISO/IEC 27001[19], IEC 62443[20]), IT service management (ITIL[21]), IT management models (COBIT[22]), as well as the current legal environment – especially the NIS2 directive[23] and its Hungarian implementation, LXIX of 2024[24], can be interpreted in the light of law. This study aims to provide a comprehensive picture of security risks[25] in industrial IT systems and to present the methodological and practical tools[26] that can be used to mitigate these risks. Special attention will be paid to network segmentation[27], regular software updates[28], Zero Trust-based access management[29], physical protection[30] and the development of incident response capabilities[31]. The purpose of the material is to provide a practice-oriented guide[32] to increasing industrial cyber resilience[33] that is useful for technical and managerial decision-makers[34].

2 Main vulnerabilities in industrial IT components

2.1 Vulnerabilities in robotic systems

Modern industrial robots are becoming more and more complex and are being used in more and more areas to automate production processes. However, because these systems operate over network connections, they provide a variety of attack surfaces for cybercriminals. The most common vulnerabilities include exploitation of remote access options, outdated software and firmware, physical vulnerabilities, weaknesses in communication protocols, and malicious firmware updates.

2.1.1 Remote access and control

A significant number of industrial robots are connected to control centres and other industrial systems via Ethernet or Wi-Fi networks. If the security settings for these

connections are incorrect, then attackers may be able to remotely control the robots, modify their operation, or even shut down the production line altogether.

Example. In 2010, a computer worm named Stuxnet[35] attacked a uranium enrichment facility in Natanz, Iran. The attackers wrote the malware specifically for industrial Siemens PLC controllers, which manipulated the operation of centrifuges. The attack destroyed thousands of centrifuges without the facility staff immediately noticing the problem. This attack was the first known instance of a cyberweapon causing physical industrial damage.

2.1.2 Outdated software and firmware

Industrial robots and their control units often operate unchanged for many years and can pose serious security risks over time due to a lack of updates. An old or unupdated firmware can contain known vulnerabilities that can be easily exploited by attackers.

Example. In 2021, a security research team discovered that several KUKA industrial robots continued to run outdated firmware, which allowed attackers to remotely manipulate robots. A penetration test succeeded in taking remote control of a robot operating on a production line, which could have created dangerous situations in a real-world industrial environment[36].

2.1.3 Physical vulnerabilities

One of the things people sometimes overlook is just how much damage someone can do simply by getting close to a robot. You don't always need a sophisticated hacking toolkit — just plugging in a USB drive and dropping the right kind of malicious code can mess things up pretty badly.

Example: Take what happened at Tesla's Fremont plant back in 2018. One of their employees got hold of the robots' control system and deliberately sabotaged it by sneaking in some harmful code. Nobody noticed right away, but the sabotage caused all kinds of production problems that only came to light later when an internal audit dug into it. Once they figured out what was going on, the worker was fired immediately. After that, the company took extra steps to lock things down physically and make sure it couldn't happen again[37].

1.1.4 DDoS (Distributed Denial of Service) attacks

Here's another weak spot you don't really think about until it happens: DDoS attacks. These things don't even touch your control systems directly — they just bury your network in so much junk traffic that everything freezes.

Example: That's exactly what happened in 2022 at a water treatment plant in the USA. Hackers pointed a botnet at the plant's SCADA system and sent a storm of requests, millions at once, until the whole operation ground to a halt. The water supply was cut off for hours, and people in the area were left high and dry. Not a great day for anyone.

Stories like these are a good reminder: it doesn't take much to cause a lot of damage when there are gaps in security. Keeping a close eye on systems, updating them regularly, and having solid defences in place isn't optional — it's what keeps everything running[38].

2.2 Network infrastructure vulnerabilities

If you think about it, the network is really what keeps an industrial plant alive. It connects everything — the machines, the control systems, the people monitoring the whole thing. But the truth is, these networks are often not as secure as you'd expect. When something slips through, it can throw the whole operation off balance. Here's what that tends to look like in the real world.

2.2.1 Firewalls that don't do their job

You'd think a firewall would protect you, right? Well, not if it's old, poorly set up, or just ignored. In lots of plants, firewalls are running with bad configurations or outdated rules that let all kinds of traffic through. And that can mean attackers walking right in and getting straight to the sensitive systems without much effort.

Example: A good example of this happened in 2019 at a car factory in Germany. The attackers simply found an open port that no one had bothered to block. They slipped in, shut down a few production lines, and the plant lost an entire shift before anyone could stop it. That single mistake cost them millions[39].

2.2.2 Weak or unprotected communication

Here's another problem: the way the machines talk to each other. A lot of plants still use old communication protocols like Modbus or DNP3 that don't encrypt anything. No passwords, no scrambling, nothing. So anyone listening in on the line can see what's being sent — or worse, send their own fake commands back.

Example: In 2021, a British water company learned this the hard way. Hackers noticed their SCADA system was using plain old Modbus, with nothing to hide the commands. They stepped in, messed with the water pressure readings, and before long one of the facilities had minor flooding. A headache they didn't see coming[40].

2.2.3 Outdated SCADA and control systems

And then there's SCADA — the brain of the whole operation. The problem is, a lot of these systems are ancient by today's standards. They don't get patched much, and they can't handle modern attacks. Which, of course, makes them an easy target.

Example: That's exactly what happened in 2022 at a U.S. chemical company. Hackers got into their network, locked up the entire control system with ransomware, and

demanded five million dollars. The company refused to pay and rolled everything back from backups, but it still took days to recover and cost them plenty[41].

When you see how easy it is for these things to go wrong, it's clear that keeping the network secure has to be a priority. Without good firewalls, encrypted communication, and systems that are actually up to date, you're basically leaving the door wide open.

2.2.4 Vulnerability to social engineering attacks

Sometimes the biggest weak spot in an industrial company isn't the technology — it's the people running it. Hackers know this all too well, and they take advantage of it by sending out convincing emails, making fake phone calls, or using other tricks to get someone to give up information they shouldn't.

Example: At a steel plant in France, for example, a senior engineer got what looked like a normal email one morning. It told him he needed to log in to an "update portal" to keep his account active. It all looked official enough, so he went ahead and logged in. Only later did they realise the site was fake, and his password had been stolen. With that, the attackers got into the plant's control system from the outside and messed with the production lines. After cleaning up the mess, the company decided everyone needed proper security training, so this wouldn't happen again[42].

2.2.5 Exploiting zero-day vulnerabilities

Then there are attacks no one really sees coming — what they call zero-day vulnerabilities. These are bugs or flaws in the system that no one knows about yet, not even the companies that made the software. There's no fix ready, no warning, and nothing much you can do once it's being used against you.

Example: That's exactly what happened to a big electronics manufacturer in Asia at the start of 2023. Hackers discovered a flaw in Windows on the company's industrial control machines that no one even knew existed. They used it to bring production to a standstill. It took the company's tech team quite a while to figure out what went wrong and patch things up before they could get the lines running again[43].

2.2.6 DDoS (Distributed Denial of Service) attacks

Most industrial networks really aren't ready for what happens when someone floods them with fake traffic. Everything just clogs up. The whole thing slows down, then stops. People usually don't even see it coming — by the time they figure out what's happening, it's already too late.

One case: In 2022, an energy company in Europe got hit. It shut down their dispatch centre for hours and left parts of several cities in the dark. Not just a random hacker either. Investigators said it probably came from a group supported by a government, with the goal of throwing critical infrastructure into chaos.

This is exactly why keeping networks in good shape is so important[44]. Updates, regular checks, and making sure people know what to watch for. Skipping that? Sooner or later, it bites you.

2.3 Other real-world stories

A few years ago, at Tesla’s Fremont plant, back in 2018, they had an insider problem. One of their own employees went in and messed with the robots. He slipped malicious code into the control system, and production went haywire. Cars came off the line with all kinds of defects. They didn’t catch it right away. It showed up later when the company ran a routine check. He was out the door immediately[45].

In 2020, Nissan’s factory in Sunderland had its turn. Hackers spotted an open port and walked right into the SCADA system running the painting robots. Nobody noticed until thousands of cars were already painted wrong. Fixing that must’ve been a nightmare[46].

And at a German security conference in 2021, ethical hackers showed just how easy it still is to take over industrial robots. They picked a KUKA model, guessed the password — which was laughably weak — and took full control. They made the robot move in ways that could have been dangerous if this weren’t just a demo. All because the firmware hadn’t been updated[47].

3 Methods for testing vulnerabilities

3.1 Passive and active network testing

When it comes to figuring out how secure an industrial system really is, there are basically two ways to look at the network: passively or actively. Both have the same goal — spotting weaknesses and possible ways an attacker could get in — but they go about it differently. And the key here is to get that information without messing up the way the system is running.

3.1.1 Passive analysis

Passive analysis is pretty much what it sounds like. You watch and record what’s already happening on the network without actually touching or changing anything. The idea is to look for anything odd in the data traffic — something that could hint at an attack or some kind of vulnerability waiting to be exploited. This kind of approach makes a lot of sense for industrial setups because those systems tend to handle really sensitive control signals and data, and you don’t want to risk interfering with them.

So what's good about it? Well, the big plus is that it doesn't disrupt anything. You can quietly collect a lot of useful information about how the network normally behaves and pick up on strange patterns over time. And if you let it run long enough, you might even see clear signs of attack strategies starting to emerge.

But it's not perfect. Since you're only watching and not poking at anything, you're limited to what shows up in the regular traffic. If an attacker is smart and manages to blend in with normal operations, there's a chance passive monitoring won't catch it in time. So while it's a useful tool, it's not the full picture.

3.1.2 Passive network analysis techniques

Passive techniques leave the system untouched. Traffic is just observed as it moves. This makes it possible to notice problems without changing anything. Packets can be saved during transmission. Later, they are checked to see what is inside — the data itself, what kind of protocols, how the messages are put together. Wireshark is usually used for this because it works well. It's also common to notice patterns that don't seem normal. A network usually behaves in a predictable way. If more traffic than usual is seen, or connections to unexpected places show up, this suggests something is off. Monitoring tools are often set up to handle this automatically. These tools watch for strange activity and warn when they find something unusual. Some compare to known attack examples, others just watch for anything outside the norm. Sometimes changes happen slowly and are only visible if traffic is watched over time. For example, a device that always talked only to local servers might suddenly start connecting to unknown servers outside the network. That usually needs to be checked.

An example happened in Germany, in 2020. A steel plant noticed one controller connecting to strange addresses. It was found that a former employee had tried to get in through VPN. After that, rules for VPN were made stricter, firewalls updated, and better monitoring added. These methods are better when combined. Passive checks alone are not enough. It is usual to also run active checks and audits as well[48].

3.1.3 Active scans

Active scans are different. Here the system is tested directly. Weak points are found before anyone else can find them. Usually these are done by trained staff or hired testers. These tests often find mistakes that passive watching misses. Things like ports left open, software not updated, bad settings. But they have risks too. If they are done wrong, they can break normal work. And they need to be approved, otherwise they can cause other problems. That's why they are planned carefully.

3.1.4 Methods used in active testing

Several methods are applied when active testing is carried out. Each serves to uncover specific weaknesses by interacting with the system directly. One method is port

scanning. Tools such as Nmap are used to check which ports are open, what services are running behind them, and even the version numbers of those services.

Vulnerability scanning is another approach. Automated programs like Nessus, OpenVAS, or Qualys run a broad analysis of the system. They compare its state against databases of known vulnerabilities and produce a report that lists potential risks.

Penetration testing is also performed. In this case, trained ethical hackers try to break into the system by hand. They use a variety of attack techniques. These often include attempts to crack weak passwords, inject malicious SQL queries, or take advantage of mistakes in how access permissions are set up.

Exploit testing goes one step further. Here the vulnerabilities that have been identified are actively exploited, though in a controlled setting. Frameworks such as Metasploit are often used to carry out these tests.

Manipulating network traffic can also reveal weaknesses. Attacks such as ARP spoofing or man-in-the-middle interception are sometimes simulated to show how communication between devices could be eavesdropped on or altered.

One example comes from 2022. At an American pharmaceutical company, a penetration test was carried out on the manufacturing network[49]. The test found that the administrator account for a SCADA system still used its default password and could be reached from outside the company. If this had been exploited, it could have allowed an attacker to change manufacturing processes and compromise the quality or safety of products. After this discovery, the company enforced stronger password policies and began regular vulnerability reviews.

4 Physical and logical security audits

Industrial IT security covers more than just defending against software and network attacks. Physical access and logical protection also need to be considered. Audits are done to find weak points and recommend actions to lower risks.

4.1 Physical security audit

A physical audit checks if critical equipment and control systems are protected against unauthorised access. This includes looking at access control, where sensitive infrastructure is placed, video surveillance, and other protective measures.

Audits are usually based on standards and legal rules. Common ones are:

- ISO/IEC 27001, for information security management, including physical aspects.
- NIST SP 800-53, from the US, also covering physical safeguards.

- IEC 62443, focused on industrial automation and control cybersecurity.
- NIS2 Directive, the EU's updated rules, requiring physical protection in critical sectors.
- In Hungary, Act LXIX of 2024, which implements NIS2 and sets national requirements for physical security in industrial systems.

4.1 Physical security audit steps

4.1.1 Access point analysis

In a physical audit, access points are checked. This means entrances, gates, locks, and other barriers. Critical areas — like control rooms, server rooms, production lines — are tested to see if access is really limited to authorised staff. Sometimes fake ID or unauthorised entry is attempted to observe how security responds.

Access control systems are reviewed separately. RFID cards, PIN locks, and biometric systems are tested. Weaknesses are noted. For example, cards that can be copied, weak passwords, or poor log review. Logs are examined for suspicious patterns.

Cameras and surveillance are checked too. Placement and coverage are reviewed. Footage storage is checked to see if it can be changed or deleted. Networked cameras are tested to see if they are protected from unauthorised remote access.

Attention is also given to critical infrastructure. This includes control rooms, data centres, network switches. Physical access to robots, control panels, and energy systems is checked to see how well they are protected from tampering or sabotage.

An audit in 2021 at a Japanese electronics factory showed several open control panels[50]. Anyone could plug in a USB stick and interfere. After this was found, stricter access rules were set and better storage for critical equipment was added.

4.2 Logical security audit

The purpose of a logical security audit is to review the configuration and operation of IT systems in order to identify potential security vulnerabilities. This includes software access rights management, password security, data protection, and compliance with applicable security protocols.

User privilege analysis: The audit assesses which users have which privileges and whether these are appropriately restricted. A common problem is that some employees have unnecessarily high levels of access, which increases the risk of abuse.

Password management policies: The audit checks whether the company has appropriate password management policies in place, such as multi-factor authentication (MFA) or mandatory regular password changes.

Software updates and patch management: The audit examines whether the software and operating systems in the system are kept up to date and whether the necessary security updates are applied.

Data protection and encryption: They check whether sensitive data is stored and transmitted with appropriate encryption. The protection of industrial control systems and customer data is particularly important.

4.3 Logical security audit and the legal environment

Logical security audit and the application of the NIS2 Directive and Act LXIX of 2024
The NIS2 Directive (EU 2022/2555) is the European Union's new cybersecurity regulation, which was transposed into Hungarian law by Act LXIX of 2024. The aim of the regulation is to establish uniform requirements for the protection of network and information systems, with particular regard to the security of critical infrastructures, such as industrial systems. During industrial logical audits, the application of NIS2 and its domestic implementation becomes essential to ensure legal compliance and cyber resilience.

4.3.1 Main guidelines of NIS2 and Act LXIX of 2024

Audits also check compliance with the key requirements set out in NIS2 and the Hungarian Act LXIX of 2024. One area is mandatory security measures. The audit looks at whether technical and organisational protections are in place. This includes logging of activity, proper network segmentation, managed access rights, and systems to detect incidents. A risk-based approach must also be verified. The law requires a documented risk analysis and clear action plans based on the risks found. The audit checks if these documents exist and if they are kept up to date. Incident handling is another point. Major security incidents must be reported to the Regulatory Activities Supervisory Authority (SZTFH) within 24 hours. The audit examines whether the company has clear procedures and practices to meet this obligation.

Finally, management responsibility is reviewed. The law expects senior managers to play an active role in cybersecurity. The audit checks if they are involved enough and if they understand the security processes properly.

4.3.2 NIS2 and the audit relationship of Act LXIX of 2024

During the logical security audit of industrial systems, NIS2 and Hungarian legal compliance can be interpreted as follows:

Documentation of legal compliance: The audit must examine whether the organisation fulfils the obligations specified by law. Non-compliance may result in significant fines and operations that jeopardise the security of supply.

Examination of reactive and proactive controls: The audit assesses not only existing security measures, but also their functionality, effectiveness, and speed of response to incidents.

Mapping critical services and dependencies: Under the law, all organisations are required to identify their critical services and their technological dependencies. These mappings and records must also be checked during the audit.

Example: During a 2024 logical security audit of a Hungarian water utility provider, an investigation conducted in accordance with the NIS2 Directive and Act LXIX of 2024 revealed deficiencies in the incident reporting procedure and management awareness. Following the audit, the organisation appointed a dedicated cybersecurity officer, introduced automatic log analysis, and updated its access rights management system.

4.4 Logical security audit and ITIL principles

Logical audits check IT system configurations. User access rights and security processes are reviewed. The ITIL framework helps make IT security and service management more consistent.

4.4.1 ITIL support areas

Incident management. This is for dealing with security incidents in industrial systems quickly and efficiently. Using ITIL principles makes sure that every incident is properly documented and analysed, so systems can be restored quickly after an attack.

Problem management. This is for investigating and eliminating recurring errors and vulnerabilities in industrial systems. The ITIL methodology enables Root Cause Analysis (RCA), which helps to increase the reliability of systems in the long term.

Change management. This ensures the controlled introduction of changes to industrial infrastructure. This is particularly important for industrial control systems (ICS) and SCADA networks, where any change can potentially pose a serious security risk.

Configuration and asset management. Ensures continuous monitoring of industrial networks and systems, guaranteeing that systems operate in a precisely documented state and that security settings are updated in a timely manner.

3.4.2 ITIL and auditing

When logical audits are done on industrial systems, ITIL principles help improve several areas. Security processes become more transparent. ITIL gives a structured way to handle incidents and apply audits consistently. Incident management and reporting are automated. Detected vulnerabilities or attacks are logged and addressed

faster. Risk and change are managed better. Changes in IT systems follow formal steps, which lowers the chance of new weaknesses.

Example: In 2023, a European car manufacturer audit showed recurring software errors in SCADA networks. Downtime was caused by faulty commands. After ITIL-based processes were introduced, problem management improved stability and reduced downtime[51].

4.5 Areas of COBIT support

Aligning corporate goals and IT goals. Industrial systems security is effective when IT processes are directly aligned with business strategic objectives. COBIT helps to ensure that technical measures are evaluated from a business perspective during security audits.

Responsibility matrix (RACI): COBIT clearly defines which actors are responsible, approve, consult or inform in the secure operation and audit of industrial systems. This is particularly important in the area of access to critical systems and incident management.

Process maturity and performance measurement. The COBIT framework allows the maturity level of logical security processes to be measured. This means that industrial audits can reveal not only compliance but also opportunities for improvement.

Establishment of a regulated control environment. In line with COBIT's control objectives, the rules and controls introduced for industrial IT systems can be examined in a structured manner, so that audits are not isolated activities but an integral part of organisational management.

3.5.1 The relationship between COBIT and auditing

When conducting logical security audits of industrial systems, the use of COBIT allows the audit to focus not only on technical errors, but also to evaluate the entire IT management and operating environment:

The relationship between management objectives and compliance controls. COBIT helps us to evaluate the fulfilment of the organisation's strategic objectives during security audits, not just regulatory compliance.

Transparent process and accountability system. The audit clarifies which actors are responsible for preventing, managing, documenting, and reporting security incidents.

Assessment of process maturity. The COBIT model helps determine the maturity level of industrial IT security processes and what improvements are needed to achieve higher reliability.

Example. During a logical security audit in 2022, IT management practices at an Eastern European chemical company were analysed in a structured manner based on the COBIT framework[52]. The audit revealed that change management and incident management documentation were incomplete, which hindered the effective handling of security incidents. The new responsibility matrix and audit log system introduced based on COBIT increased accountability and made it possible to trace recurring problems back to their root causes.

4.6 Areas supported by ISO/IEC 27001

Risk-based approach. Through risk assessment, which forms the basis of industrial system security, ISO/IEC 27001 enables organisations to identify, evaluate, and manage relevant threats and vulnerabilities.

System of security controls. Based on the ISO/IEC 27002 control catalogue associated with the standard, the implementation of specific measures (e.g., encryption, access management, incident management) becomes mandatory, which significantly strengthens the protection of industrial systems.

Documentation and compliance. Detailed policies, process descriptions, and logging requirements are introduced within the ISMS to ensure continuous auditability.

Continuous improvement (PDCA cycle). The Plan-Do-Check-Act cycle required by the standard ensures that the security of industrial systems is continuously improved in line with the changing technological and threat environment.

4.6.1 The relationship between ISO/IEC 27001 and auditing

When auditing the logical security of industrial systems, the application of ISO/IEC 27001 allows the audit to be conducted according to objective, standards-based requirements:

Development of an auditable control system. The controls specified in the standard enable formal examination of IT operations and security measures.

Compliance and certification. ISO/IEC 27001 certification confirms that the company meets international expectations, which can be an advantage during supplier or government audits.

A full life cycle approach. ISMS not only examines current operations, but also integrates risk prevention, incident management, and post-incident analysis into the security system.

Example. During a logical security audit in 2023, a Hungarian food manufacturer was able to manage network access control and supplier risks in a more structured manner after implementing an ISMS in accordance with the ISO/IEC 27001 standard. The audit showed that standardised incident management procedures and regular risk

assessments reduced the possibility of unauthorised access to critical production data and improved the organisation's response time to security incidents.

The application of ISO/IEC 27001 during industrial logical security audits provides a structured, verifiable, and internationally recognised basis for cybersecurity compliance. Standardised controls, documentation, and continuous improvement requirements help organisations develop their security measures in a strategically and operationally sound manner. It is particularly important for industrial players to integrate the principles of ISO/IEC 27001 into their IT management, as this strengthens business continuity and cyber resilience in the long term.

Physical and logical security audits play a key role in protecting industrial systems, as they help identify risks of unauthorised access, configuration errors, and data security issues. It is essential for industrial companies to conduct these audits regularly and continuously update their security measures in order to prevent potential threats and attacks.

5 Automated vulnerability testing

Automated testing is used to find security gaps in industrial systems. Quick, efficient. Networks, control units, and other components are scanned without manual effort. Regular use reduces human mistakes. Gives a clear picture of security status.

5.1 Vulnerability testing tools

Automated scanners: Nessus, OpenVAS, Metasploit. Find known vulnerabilities. Classify severity (CVSS). Produce reports with fixes.

Works well in large plants. Many devices are checked at once. SCADA, PLC, HMI. Example: 2021, French food plant. OpenVAS audit found outdated SCADA firmware[53]. Vulnerabilities public. Systems updated. Network defences improved.

5.2 Manufacturer-specific security tests

Systems used in industrial environments often use proprietary manufacturer protocols and unique configurations that differ from those used in general IT systems. Special industrial security testing tools are used to test these unique systems, taking into account the specific operating characteristics, protocols (e.g., Profinet, Modbus, EtherCAT), and topologies of the industry in question (e.g., automotive, energy, pharmaceutical).

Example: In 2020, internal security tests conducted by a German automotive company revealed that the Siemens control system they were using contained a previously undocumented security vulnerability that would have allowed attackers to send unauthorised commands to robots[54]. As a result of the test, the company began working more closely with the manufacturer to improve the security of the system.

5.3 Fuzzing testing

Fuzzing sends random or incorrect data to system inputs. The goal is to find weaknesses an attacker might use. Works well on industrial protocols and hardware. Can expose unexpected errors or buffer overflows.

Example: 2019, American energy company. Fuzzing test showed critical protocols failed on specially formatted data. A crafted packet could shut down a control server. Company responded with software updates and new protection measures[55].

5.4 Red Team and Blue Team exercises

Red Team (attacker) and Blue Team (defender) exercises are used more often in industrial security. Red Team tries to break into the system like a real attacker. Blue Team defends and improves protection. These tests show technical gaps, human errors, and how staff react.

Example: 2022, American chemical company. Red Team found a weak spot in the manufacturing network. Attackers could have changed chemical dosing[56]. Blue Team responded with new firewall rules and closer monitoring of access attempts.

Case study: 2021, American pharmaceutical company. Ethical hackers tested the control system. Default passwords were still in use. Attackers could have changed production[57]. Afterward, the company improved password policies and made audits of networks regular.

5.5 Network segmentation and security protocols

VLANs and zoning in industrial networks. Network segmentation allows different systems, such as production, administration, and maintenance segments, to operate separately, thereby reducing the chance of lateral attacks spreading. The use of virtual LANs (VLANs) and DMZs enables stricter access control and allows industrial automation networks (e.g., SCADA, DCS) to be separated from office IT systems.

Example. An Italian automotive supplier in 2022 segmented its production line PLCs from the administrative network by introducing VLANs [58]. After this step, during a simulated internal attack, the attackers were unable to access the control technology devices and only reached the office system.

5.6 VPN and encrypted communication

VPN is needed for remote access to industrial systems. Encrypted connections stop sensitive data from being intercepted or changed. Secure protocol versions (like TLS, DTLS) should also be used. Applies to industrial protocols such as Modbus/TCP and OPC UA. Helps prevent attacks.

Example: 2023, energy industry audit. Maintenance staff were still using unencrypted remote access. VPN was made mandatory. Logging improved. Data security increased[59].

Network segmentation and encrypted protocols are key defences. Together they support Zero Trust setups. Every connection is treated as untrusted by default.

5.7 Regular software and firmware updates

In industrial systems, it is generally required that software and firmware updates are applied regularly. But in reality, this is not always done as it should be. Updates can be delayed for weeks, or even skipped entirely, which leaves the systems exposed to vulnerabilities for longer. For this reason, automatic update systems are often chosen instead. These are set up so that updates from a trusted source are downloaded and installed at specific times. Once installed, these mechanisms do not require much additional work from staff.

Before each update is actually installed, some checking is done. Version numbers are compared, and compatibility tests are carried out as well. If something goes wrong after the update, the system can usually be rolled back to the earlier state, which is important because downtime can otherwise be quite damaging.

Example: A company in Finland that produces logistics automation equipment set up a central control system to keep their production line controllers updated. The system checked for firmware changes and installed them automatically[60]. This reduced the risk of hackers exploiting old software, and over time they also saw fewer operating errors.

5.8 Developing patch management strategies

For patching, it is usually suggested to start with a full list of the devices and systems in place. Then all weaknesses are divided into four levels: critical, high, medium, and low. This way, the most serious ones can be handled first.

When a patch is available, it is first tested in a separate, closed test environment, often called a sandbox. This testing is done before anything is changed on the real system. Then a timetable is set up, and all steps are planned so that staff are told what will

happen, and when. After the patch is applied, feedback from users and operators is collected and added to improve the process next time.

Example: During an audit in Spain in 2022, it was found that PLC devices were still using old firmware. After this, the company put in place a central system to track firmware versions and send warnings when updates were ready[61]. They also decided to do a weekly check to make sure patches were applied. This lowered the risk of zero-day attacks and made the systems run more reliably.

5.9 Multi-factor authentication and access management strategies

The Zero Trust security model is based on the idea that no user or device on the network is trusted by default. Every access request is checked and controlled. This applies even when the request comes from inside the network. In industrial environments this is especially important. Unauthorised access, such as from an uncertified workstation or maintenance laptop, can directly affect physical processes. As part of Zero Trust, systems are segmented. Authorisation is given based on access level. Continuous authentication is also used.

Example: At a Belgian chemical plant in 2023 the Zero Trust model was implemented. VPN use was required for all access. Multi-factor authentication was also added, together with device fingerprinting. After this, the number of unauthorised access attempts went down. The resilience of IT systems was improved as well[62].

5.10 Role-based access control (RBAC) and privilege minimisation

The RBAC model ensures users only have access to what they need for their specific role. During audits, it is often seen that rights are too broad. This happens especially with long-term employees or staff who have changed roles. The aim of privilege minimisation is to follow the least privilege principle.

Example: In 2022 an audit was carried out at a Hungarian food company. It was discovered that production managers had full administrator rights on the SCADA system. After the audit, RBAC was introduced. Jobs were matched to clear privilege levels. After changes were applied, security improved. Fewer accidental configuration errors were also reported[63]. Combining multi-factor authentication and role-based access management is now a standard element in industrial security. It increases protection against cyber threats. It also improves transparency, compliance, and how incidents are handled.

6 Implementation of physical security measures

6.1 Physical isolation of critical systems

In industrial settings, critical systems are usually kept apart from others. This means control stations, SCADA servers, also data collection devices. They are separated from normal workstations and from rooms that can be accessed freely. For this, closed server rooms are created. Access is kept limited. Cabinets or even safes are used for sensitive equipment. The goal here is to make sure even someone inside the company but without permission cannot reach these systems. This lowers the chance of direct tampering or someone leaking data.

Example: At a Polish chemical plant in 2023, it was seen during an audit that SCADA terminals were left out in the open, in the factory hall. Anyone walking by could have used them. To fix this, separate containers were put next to the production line. These containers had locks[64]. Only technicians who were authorised could get inside. After this was done, the risk from insiders was much lower.

6.2 Use of biometric and card access control systems

Modern ID systems are used to keep critical rooms secure. Fingerprint readers and face recognition are often used. RFID cards are also common. These systems make sure only people with permission can enter. Logs are kept, showing who entered, when, and how long they stayed. This can help prevent problems and also figure out what happened later if something goes wrong.

Example: In 2022, a German automation company added a biometric access system for its control rooms. The system used hand geometry scans. After it was added, staff followed rules better. Fewer people tried to enter without permission[65].

It is clear that good physical security is an important part of protecting industrial systems. These extra layers make it harder for attackers to get in by just walking up to the equipment instead of hacking.

6.3 Continuous monitoring and incident management plan development

6.3.1 Use of SIEM systems to detect real-time threats.

Security Information and Event Management (SIEM) systems play a key role in industrial environment security, as they are capable of collecting, analysing, and correlating security logs from various sources (e.g., firewalls, endpoint protection

systems, SCADA logs) in real time. SIEM systems generate automated alerts when they detect a suspicious event, thereby significantly reducing the time between detection and response (reducing MTTD/MTTR metrics).

Example: In 2023, a Dutch pharmaceutical company installed a SIEM system between its ICS and corporate IT systems. A wave of failed login attempts was immediately detected by the SIEM correlation rules, allowing the IT department to block the affected IP address ranges before the attack escalated[66].

6.3.2 Establishment of an Incident Response Team (IRT) and rapid response protocols

An Incident Response Team, or IRT, is usually set up when incidents need to be handled properly. The team is supposed to work based on written protocols, which are prepared before anything happens. These protocols usually say how incidents are classified and also who is responsible for what. They also describe first actions to take and which communication channels to use. A post-incident check is also part of the process. In industrial systems, this setup is very important because it helps keep production running and protects data at the same time.

Example: In 2022, one SCADA station at a Hungarian electronics company was hit by ransomware. The IRT followed the written protocol and first isolated the network, which they did in three steps. Then they restarted the backup. Later, when forensic work was finished, access policies were updated too. Because the response was fast, no serious production loss was reported[66].

Monitoring and incident response are not just useful for reacting quickly. They also help the organisation to learn from each event and also get better prepared next time, which is why resilience can improve over time.

Conclusions

Industrial systems have changed a lot in recent years. More parts are connected now. Robotics, control units, networks. All tied together. This makes production faster and more efficient. But it also opens up more risks. Weaknesses that were not there before are now part of the system. Attackers have more ways in. Problems can hurt production, cause delays, damage equipment. Even put people in danger.

This study looked at these risks. There were examples of what went wrong. Outdated firmware. Bad passwords. No network segmentation. Not enough monitoring. Insider sabotage. Ransomware. Phishing. Many different problems. Not just technical. People make mistakes too. Organisations don't always follow rules.

What can be done? Many things. Systems need checking often. Both passive watching and active testing help. Physical audits are important. Logical audits too. Automated scanners can find problems fast. Segmentation helps. Zero Trust helps. RBAC and

MFA should be used. SIEM systems can watch for attacks. Software and firmware must be kept up to date.

But it is not just about tools. Security needs to be part of how the company works. Managers must care about it. Staff must know what to do. Standards help. ISO/IEC 27001. NIS2. ITIL. Training helps. Planning helps.

Security is never finished. New threats keep coming. Only by combining technology, rules, and good management can companies stay safe. It takes regular work. Learning from mistakes. Fixing weak spots. This is how resilience is built. Step by step. Over time.

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Cybersecurity and user challenges in the digital age: parallels between BYOD and self-driving cars

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Abstract: The rapid spread of digital technologies has brought many new opportunities, but at the same time it has created serious security risks. The aim of this study is to present the common risk patterns of Bring Your Own Device (BYOD) practices and self-driving cars in the form of a literature review. Although the two areas appear to be far apart, they share similar problems: network vulnerabilities, lack of user awareness, and regulatory and management dilemmas. In the case of BYOD, the main threats are data theft, malware, and shadow IT, while in the case of self-driving cars, they are software updates and the manipulability of sensors and communication systems. In both areas, increasing user trust and awareness is key, as technological protection alone is not enough. Regulation and management also play a crucial role: without a proactive, risk-sensitive approach, security cannot be guaranteed. The study concludes that the strategies and attitude studies developed in the world of BYOD can serve as lessons for the social and technical introduction of self-driving cars, while the complex ecosystem of AVs can also provide new perspectives on corporate information security.

Keywords: BYOD (Bring Your Own Device), Autonomous Vehicles, Cybersecurity, User Awareness, Regulatory Challenges)

1 Cybersecurity risks: parallels between BYOD and self-driving cars

The development of digital technologies has accelerated rapidly in recent decades, creating previously unimaginable opportunities while also bringing new vulnerabilities. Parallel to the spread of digitalization, everyday and organizational

operations have become increasingly dependent on networks, data flows, and interconnected systems. This trend is particularly evident in two areas: on the one hand, in the increasingly widespread Bring Your Own Device (BYOD) practice in companies, and on the other hand, in the rapid development and spread of autonomous vehicles (AVs). At first glance, these two areas may seem very distant from each other: while one is related to the IT environment at work, the other is linked to the future of transportation. However, a closer look at the results of the literature reveals that both areas share a common focus on managing cybersecurity risks, protecting sensitive data, and mitigating system-level vulnerabilities. Based on these reviews, it is clear that whether it is the security of corporate data assets or the safety of transportation, user awareness, preventive measures, and an appropriate regulatory framework play a key role in all cases.

In a BYOD environment, organizations allow or tolerate employees to use their own personal devices—typically smartphones, tablets, or laptops—to perform work tasks. This practice has several advantages: on the one hand, it reduces costs for the company, as fewer work devices need to be provided, and on the other hand, it increases flexibility, as employees can work on the devices they are accustomed to using. At the same time, the literature clearly points out that this model increases the attack surface of organizations and presents IT security professionals with new types of threats. Research highlights that the most common risks include the loss or leakage of sensitive data, the emergence of malware and viruses, unauthorized access, and the use of weak or incomplete authentication procedures (Ratchford, 2022; Yeboah-Boateng & Boaten, 2016). In addition to these, the phenomenon of shadow IT poses a particular problem, whereby employees circumvent official IT regulations and use applications or services that are not authorized or controlled (Wani et al., 2020). Researchers emphasize that in order to mitigate risks, it is necessary to introduce modern technical solutions, such as mobile device management, data transfer and storage encryption, and strict access control (Ratchford, 2022).

The risk factors associated with self-driving cars are based on similar logic, as these systems also rely on extremely complex IT networks that are vulnerable due to their openness. The operation of AVs is fundamentally enabled by advanced sensors, artificial intelligence, and continuous network communication, such as V2X (vehicle-to-everything) data connections. However, this openness brings with it the risk of cyberattacks: there is a real threat of vehicle control being taken over, data leaks, GPS signal manipulation, or even disruption of the entire transport system (Nayak, 2024; Youssef et al., 2024). The targets of attacks can be diverse: on-board control units (ECUs), software update channels, or even data exchange between the vehicle and external infrastructure (De Vincenzi et al., 2024). However, according to experts, the security of the AV ecosystem cannot be treated solely as a technical problem. To ensure real protection, it is necessary to conduct a comprehensive, system-level assessment of risks, set appropriate priorities, and ensure legal and regulatory compliance (Lim et al., 2024).

The parallel between the two areas can best be seen in the fact that in both corporate BYOD practices and the world of self-driving vehicles, the vulnerability of network-based technologies and a lack of user awareness are decisive factors in determining the level of security risks. Just as it is common for employees to underestimate the importance of security regulations and data protection in the case of BYOD, it can also be a problem with self-driving cars if users place excessive trust in the system or deliberately circumvent the rules (Ratchford, 2022; Nayak, 2024). All this points to the need for a proactive and preventive security policy in both areas. Such a policy can only be truly effective if it combines state-of-the-art technical protection solutions with continuous user training and awareness-raising, as well as the creation of an appropriate institutional and legal regulatory framework.

2 User awareness and attitudes: parallels between BYOD and self-driving cars

One of the biggest and most complex challenges in the safe use of technological innovations lies not only in the advanced technical background, but at least as much in user awareness, risk perception, and related attitudes. Even with the most modern security protocols and protection systems in place, if users do not understand or do not consider it important to follow the rules, the technology will remain vulnerable. In the case of both BYOD practices and autonomous vehicles (AVs), the central question is how people perceive the potential dangers, how much trust they have in the technology, and how they shape their everyday usage habits. In other words, the acceptance and safe operation of technology is not merely a technical issue, but is deeply embedded in user behavior and social attitudes.

Research on BYOD environments consistently shows that employees tend to underestimate the critical importance of data security. In many cases, convenience and quick access are more important to them than strict compliance with the rules. This attitude often manifests itself in risky behavior, such as using weak passwords, neglecting multi-factor authentication, or even deliberately circumventing company policies (Ratchford, 2022). Research shows that compliance with security regulations often takes a back seat to short-term benefits associated with fast and unhindered work (Yeboah-Boateng & Boateng, 2016). The phenomenon of shadow IT—when employees use unauthorized applications and services—is a particularly good illustration of how user attitudes often run counter to organizational expectations. In the interests of efficiency and flexibility, employees often take on additional risks, even if this directly increases the organization's data security threats (Wani et al., 2020).

In the case of self-driving cars, user attitudes also play a decisive role in safe use and social acceptance. Research shows that for most people, the most important factor is perceived safety: if AV technology is considered safe, they are much more likely to

accept and try it (Prasetio et al., 2023). However, the opposite is also true: safety concerns and lack of trust can be a major barrier to widespread adoption and slow down social integration (Moody et al., 2020; Naiseh et al., 2024). Users' perceptions are strongly influenced by their familiarity with the technology and their experiences with it. The more familiar they become with autonomous driving, the more willing they are to try it and the more tolerant they are of the risks (Khoeini et al., 2022). This means that social learning and gradual introduction can contribute significantly to the acceptance of AVs.

Trust and responsibility are particularly important factors in both areas. In a BYOD environment, it is often observed that employees shift responsibility from themselves to the organization, believing that it is the company's job to provide adequate protection. In the case of self-driving cars, research shows a mixed picture: some users place excessive trust in the technology and are therefore inclined to ignore the potential dangers, while others do the opposite, i.e., they are overly skeptical and therefore tend to reject the system (Mutzenich et al., 2021). Both extremes carry risks: excessive trust can lead to careless use, while excessive fear can lead to rejection of the technology, which also hinders the development and social utilization of innovation.

Based on a summary of the literature, it is clear that user awareness, trust, and attitude management are not solely technical issues, but require an interdisciplinary approach. Research methods used in the BYOD environment, such as questionnaire surveys of risk perception and risk-taking (Ratchford, 2022), can be easily adapted to the world of self-driving cars, where the examination of social acceptance and safety perceptions is also of central importance (Olayode, 2023; Nazari, 2024). This suggests that lessons learned in different areas of technology can be mutually beneficial, and that consciously shaping user attitudes is an essential prerequisite for the successful and safe introduction of both corporate and transportation innovations.

3 Legal, regulatory, and management aspects: BYOD and self-driving cars

Nowadays, technological progress not only poses new challenges for society and organizations in purely technical terms, but also generates serious tasks at the legal, regulatory, and management levels. The rapid pace of innovation often outstrips the adaptability of legislation and management practices, resulting in regulatory responses that are often slow and reactive. This is particularly evident in two areas: the Bring Your Own Device (BYOD) practice that is becoming widespread in companies and the rise of autonomous vehicles (AVs). Although the two areas have different operating logics, what they have in common is that they create new situations to which the legal and institutional toolkit can often only adapt retrospectively.

When it comes to BYOD, one of the most significant dilemmas for corporate management is how to strike the right balance between the benefits of flexibility and security requirements. The use of personal devices can increase work efficiency and contribute to employee satisfaction, but it also carries clear risks in terms of both data security and legal compliance (Ratchford, 2022). In addition, organizations face compliance obligations such as the GDPR data protection regulations or the NIS2 cybersecurity directives, which place a heavy burden on management. The challenge is particularly acute in that the organization is also responsible for protecting company data stored or processed on employees' privately owned devices (Enterprise Defense, 2023). Research emphasizes that a successful BYOD policy cannot be limited to technical protection, but must also take into account legal and ethical considerations, such as the fair treatment of employees and the fundamental right to data protection (Lam, 2024).

In the case of self-driving cars, the regulatory and legal challenges are even more complex. One of the central issues is determining liability: who bears the consequences of a possible accident—the vehicle owner, the software developer, the vehicle manufacturer, or perhaps the transportation authority? (Nayak, 2024). According to the literature, the safety ecosystem of AVs can only function reliably if there is a clear and detailed legal framework governing data collection, data transmission, and the process of system updates (De Vincenzi et al., 2024). In the case of software-controlled vehicles, special attention must be paid to the control of software updates, the security of the supply chain, and the management of risks associated with third parties. These factors pose significant risks not only from a technical perspective, but also from a legal and management perspective (De Vincenzi et al., 2024). The establishment of an appropriate regulatory framework is therefore a prerequisite for the safe social and economic introduction of self-driving vehicles.

4 Summary and future research directions

A review of the literature examining the cybersecurity, user, and regulatory aspects of BYOD and self-driving vehicles clearly shows that, although the two areas appear separate at first glance, they are in fact closely related in many ways. The common denominator is provided by three key factors: the presence of cybersecurity risks, the role of user awareness and attitudes, and regulatory and management challenges.

Future research should move in several directions. On the one hand, a deeper and more systematic examination of the effectiveness of user awareness programs is needed. On the other hand, interdisciplinary approaches are needed that can combine technical, legal, management, and social science perspectives. Thirdly, emphasis should also be placed on harmonizing international regulatory frameworks, as digital technologies by their very nature do not stop at national borders (Lam, 2024; Kaufman, 2022; Nayak, 2024).

Overall, comparing the two areas offers an opportunity to develop comprehensive and integrated security models that address technical vulnerabilities, user factors, and regulatory challenges simultaneously. This holistic approach will be key to ensuring that digital technologies become truly secure, reliable, and widely usable in the future. The examples of BYOD and self-driving cars clearly show that the success of innovation depends largely on whether technical solutions can be successfully integrated into legal and institutional

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From compliance to strategy: How companies turn sustainability into action

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Abstract: The development of the EU Sustainability Reporting Directive (CSRD) and the European Commission's Omnibus initiative, launched in February, are impacting companies' practical sustainability efforts. As existing regulations and laws affect companies' sustainable development, the VALIOT project companies have outlined and considered concrete measures regarding the impacts of sustainable development in practical business. The companies have utilized VRIO, PESTEL, and 8-field analyses to determine the concrete implications of sustainability factors. This article discusses influential and relevant sustainability factors for case companies to meet their stakeholders' current and future demands.

Sustainability, PESTEL, SME, VRIO, 8-Field analysis

1 Introduction

The transition to a green economy guided by climate policy is significant across sectors and in the structural changes within them. These changes will affect companies' strategies and investment decisions, among other things, fostering innovation and improving productivity and competitiveness. Environmentally friendly practices can simultaneously enhance environmental sustainability and economic efficiency. [1]

The Corporate Sustainability Reporting Directive (CSRD) was published in the Official Journal of the EU in December 2022 and entered into force in January 2023. [2] It was supposed to usher in a new era of corporate openness and contribute to the sustainability transition of the EU economy by providing financial incentives for companies to achieve Europe's sustainability goals. The Corporate Sustainability Reporting Directive was considered necessary for data availability, comparability, and reliability. At the same time, companies' reporting costs would decrease in the long term, and, among other things, overlapping standards would be reduced [3].

An organization's intangible resources include, for example, the expertise, reputation, and motivation of employees, and financial resources include assets such as equity, risk tolerance, and liquidity. When evaluating these resources, consider where the organization is more successful than its competitors, what actions or strategies have enabled this success, and which resources support these actions or strategies. A company's competitive advantage can result from strategic investments in education and professional development, creating a skilled workforce. This valuable, untraceable resource is efficiently integrated into the company's operations. Strategic business studies for SMEs should consider the need to use practical tools for assessing a company's environmental, economic, and social responsibility.

In this study presentation, we are focusing on the meaning of combining CSR and business strategy in SMEs. SMEs play an essential role in achieving the Sustainable Development Goals, e.g., given their number and their significance in employment. Studies combine theory and practice to enhance and promote responsible business practices, develop competence to promote EU and global sustainability goals, and maintain companies' competitiveness. In connection with Omnibus I, SMEs are considering, among other things, postponing sustainability reporting measures, which may weaken competitiveness and stakeholder cooperation, or lead to a decrease in customer numbers. SMEs use, for example, VRIO, PESTEL, and 8-SWOT analyses to responsibly develop strategic business, focusing on the company's business environment and related information retrieval. Based on current-state analyses, the business was considered and analyzed from sustainability and responsibility perspectives, using, among other things, the Blue Sea strategy [4]. A broader picture of business responsibility, its development, and its practical interests was formed through articles, podcasts, and video assignments produced in the Green Responsibility project [5]. The study is based on the VALIOT project of Laurea University of Applied Sciences and LAB University of Applied Sciences in Finland. The project is funded by the European Union (ESR+ funding) and runs for 2 years (2023-2025).

2 Theoretical background

2.1 Sustainability and ESG in the sense of strategy

Considering sustainability and ESG factors to support companies' operations should be incorporated into the national strategy to ensure a clear fiscal planning framework and sustainability reporting. [6] The key question is how SMEs achieve long-term sustainability goals and meet society's requirements through implementing sustainable development. Those companies that can commit to and integrate ESG (environmental, social, and governance) into their operations can achieve long-term sustainable

growth. Focusing on core business issues creates a picture of what works and what does not in the company. These key decisions guide management and experts in business value chains. [7] SMEs' commitment to sustainable development is essential, as they are responsible for around 70% of global pollution. [8] Many SMEs and their staff have not understood how the seventeen components of these SDGs [9] relate to practical business and how they are reflected in the development and assurance of competitiveness. Sustainable development and social responsibility are not as deeply rooted in mainstream business education as environmental issues. [10]. Social responsibility should be considered from several perspectives when looking at business comprehensively, because human dignity and equality for all are basic norms. [11].

Organizational sustainability refers to forming business strategies and practices that promote sustainable development. [12] and high-performance and sustainability practices as part of business strategies [13] and operational strategy [14]. Calza et al. [15] highlight the importance of customer experience and sustainability in corporate value creation, while Kishita et al. [16] emphasize sustainability as a core value from a stakeholder ESG perspective, and McColl-Kennedy et al. [17] recall the importance of customer experience in increasing competitiveness and customer satisfaction. Evans et al. [18] consider recognizing changes in business models as a fundamental approach to implementing innovations for sustainable development. The concept of sustainability performance underpins the analytical framework for sustainable innovation. Further, it is a process that integrates sustainability, ecological, economic, and social aspects from ideation to commercialization, increasing economic growth. [19]

Malesios et al. [20] discuss in their article "Do Sustainability Practices and Performance Affect SME Growth? What specific sustainability aspects affect the financial performance of an SME? From the point of view of statistical modeling, what is the most appropriate combination between the latter?" Companies pay attention to sustainability—for example, to achieve lower costs, recruit and retain environmentally conscious employees, build a positive image and reputation, increase sales among consumers who recognize green values, or position themselves as sustainability pioneers. [21]. A study by Nidumolun, Prahaladin, and Rangaswami [22] concluded that reductions in the costs of environmentally friendly companies were achieved through decreased production inputs. Organizations strive for sustainability for profitability, environmental policies, and stakeholder pressure [23]. In other words, the most important motivator for companies to achieve sustainability is competitive advantage and improved profitability [24].

Organizations must explore how to strategically and efficiently align sustainability and innovation to create value for themselves, stakeholders, and society. SME innovation ecosystems play an important role in creating sustainable innovations by enabling flexible responses to needs and challenges. [25] The company's management must ensure personnel's competence, for example, in the analysis tools used to interpret

responsibility requirements, so that the company's achievement of a competitive advantage is sufficient. [26]

2.2 Omnibus I

The sustainability reporting requirements introduced in recent years have been considered unreasonable, for example, in terms of the triangular taxonomy and the number of approximately one thousand data points [27], which is why the European Commission published the Sustainable Development Summary Package ("Omnibus I") [28] on 26 February 2025. It postpones the implementation and application of the Corporate Responsibility Directive, and, for example, the obligation to identify and manage a company's harmful environmental impacts would be limited to the company's direct business partners. The implementation of the CSRD Directive for second- and third-tier companies was postponed for 2 years. [29] In February 2025, the European Commission proposed its first sustainability roll-up package to simplify and dismantle the EU's current sustainability regime (reporting). [3] The Omnibus I package dealt with the regulations on sustainability reporting in the context of the Taxonomy Regulation, and the initiative, among other things, removed SMEs from the scope of reporting obligations and introduced an additional limit of 1,000 employees for all other large companies, which would reduce the number of obliged entities by 80%. The Commission's proposal postpones the mandatory CSRD for two years for the second and third waves. Reporting requirements for SMEs by contractual partners in value chains would be streamlined and harmonized, and information could be requested from smaller companies in the value chain based on EFRAG's VSME voluntary reporting standard. In addition, the ESRS reporting standards would be simplified and clarified. The measures to specify the regulations will continue in 2025. [29]

Omnibus I remains an initiative of the Commission, not a binding legislative amendment. Still, it will affect the overall atmosphere, and lighter guidelines will be adopted following consideration by the European Parliament and the Council. Omnibus I does not change the fact that promoting sustainable development is still relevant and can be one of the company's means of differentiation and a source of competitiveness. Discussions with SMEs in the VALIOT project have revealed that companies that have already invested in measures from a sustainable development and sustainability reporting perspective will continue to promote them to maintain competitiveness, among other things.

3 Methodology

The VRIO analysis emphasizes the need for continuous refinement to maintain competitiveness, and customer satisfaction, for example, plays a key role in assessing

resources. Regular measurement and consideration of customer experience and expectations increase perceived value and strengthen customer loyalty, as in Lean development, where, according to Byrne [30], continuous development promotes business operations. By managing strategically valuable, inimitable, and organized resources, companies can adapt to changing operating environments and remain competitive. The VRIO analysis provides a basis for understanding and utilizing internal strengths. This ensures long-term success in dynamic business environments. Barney [31] developed the VRIO analysis as a strategy tool to assess an organization's internal resources for potential competitive advantage. VRIO consists of value, rarity, replicability, and organization, which guide the evaluation of resources for sustainable competitive advantage. In other words, VRIO helps to assess internal resources and the potential for competitive advantage.

The PESTEL analysis was chosen as a tool in the VALIOT project to help SMEs better understand external sustainability factors and identify the significance of direct and indirect factors. To understand the business environment and facilitate planning, political, economic, social, technological, environmental, and legal aspects and their effects on the daily business operations of SMEs are concretized. [32.] This helps consider the big picture—for example, from the Double Maternity Assessment (DMA) perspective—identifying which factors are sufficient and essential for strategic business. With this, the most critical and future-relevant external responsibility goals of an SME emerge when considering strategic objectives to ensure competitiveness. At the same time, an analysis of the business's current state is conducted, taking into account external obligations and requirements and their impact on the business's strategy. [33].

An 8-field SWOT analysis was used to map the SME's internal responsibilities and analyze development targets. When examining the company's internal factors, the significance of personnel competence from the perspectives of relevant business factors, stakeholders, and the business environment's goals is further strengthened. The analysis focuses on the sustainability aspects most pertinent to practical business and their strategic impact on meeting stakeholder requirements. In addition, the significance of success factors and crises for responsible business is analyzed, and related foresight measures are developed to maintain and develop business and competitiveness.

The 8-field SWOT analysis emphasizes the SME's internal responsibilities and the importance of personnel's competence.

INTERNAL CURRENT SUSTAINABILITY LEVEL	1. Definition and analysis of sustainable strengths. <i>The focus is on assessing and defining responsibility, sustainability data, and related processes and competencies in the company.</i>	2. Definition and analysis of sustainable weaknesses. <i>The focus is on assessing and defining responsibility, sustainability data, and related processes and competencies in the company.</i>
EXTERNAL FUTURE SUSTAINABILITY LEVEL	3. Definition of future sustainability opportunities. <i>Based on future scenarios, future opportunities related to competence in responsibility and sustainability data processes are defined.</i>	5. Naming sustainable success factors. <i>Future success factors are built by strengthening existing responsibility expertise, which can be utilized to turn opportunities into future successes.</i>
4. Anticipating and assessing future threats for sustainable actions in business. <i>In addition to future opportunities, it is important to anticipate and assess potential threats related to future visions of responsibility and sustainability information and the threats arising as a result.</i>	6. Strengthening weaknesses and responding to sustainable demands. <i>Weaknesses regarding responsibility and sustainability information must be strengthened and addressed with opportunities.</i>	7. Responding to threats against sustainable business. <i>Efforts should be made to react to future threats using existing strengths of responsibility. Identify how existing strengths can be used to turn likely threats related to sustainability and sustainability data into opportunities and improve related activities.</i>
	8. Definition of crises in sustainable business. <i>Weaknesses from the perspective of responsibility and sustainability data may become more acute, or threats may become a reality. What are these crisis situations in practice and how should we prepare for them?</i>	

Figure 1.

Sustainability and sustainability data 8-field SWOT analysis framework, paraphrase [34].

The 8-field SWOT analysis proceeds numerically from 1 to 4. From point 5 onwards, measures essential to internal and external factors are systematically considered, utilizing internal strengths and addressing identified weaknesses. After reviewing all eight fields, the contents of fields 6 and 7 will be combined into development measures to be implemented, after which preventive measures will be taken in the event of potential crises. [34]

4 Results

The results of the corporate responsibility and responsible business strategy studies aimed at SMEs were an increase in the personnel's responsibility competence, a deeper understanding, and the perception of corporate responsibility and sustainable development, and measures as part of practical business, such as the modeling and implementation of processes from the perspective of responsibility. Using the VRIO, PESTEL, and 8-field SWOT analyses, it was possible to develop an overall picture of the company's sustainable development and responsibility framework within its operating environment. Attention was paid to sustainable economy and investments, as well as to the economic, social, and environmental factors to be considered in decision-making. In addition, sustainability reporting and other regulations affecting companies' operations, reporting, responsibility, and sustainability factors were considered. The participants identified key development targets and concrete measures to develop the company's responsible business. Based on the analyses, the companies can use the development plans and analyses in practical business after the project has

ended, e.g., in investments, updating CSR in business strategy, personnel competence, mapping and drawing processes, and the CSR aspect.

In the VALIOT project, participating companies conducted VRIO analyses to identify the factors that contributed to their competitive advantage. The participants' goal was to identify and leverage the most valuable resources for strategic planning. The PESTEL analysis was used to identify external sustainability opportunities related to the company's operating environment, including regulatory requirements. An easy-to-use PESTEL analysis is not always the best way to analyze. In this context, PESTEL provided a starting point for assessing the company's sustainability framework as a current-state analysis from an external-factors perspective.

In the PESTEL analysis, companies mapped the factors affecting their business beyond their operating environment, including political, economic, social, technological, and legal aspects. This increased understanding of the significance of external factors affecting sustainability and responsibility in everyday business. At the same time, factors that directly or indirectly affect the operating environment of SMEs, EU directives and regulations, and the effects of megatrends, were identified. In addition, the development defined the necessary measures to meet stakeholders' requirements and considered the limitations, causes, consequences, and obstacles associated with strategic operating methods. The aim was to gain a competitive advantage by developing the areas of responsibility and sustainable development, and by identifying positive solutions and anticipating weaknesses and bottlenecks. The 8-field SWOT analysis, used in the strategic development of sustainability for SMEs, focused on the most essential aspects and impacts of practical business from a sustainability and strategy perspective to meet stakeholder requirements.

Conclusions

The VALIOT project's strategic business reviews and analyses of its business environment through VRIO, PESTEL, and 8-field SWOT analyses increased the participants' sustainability competence and understanding of the strategic importance of sustainable development. By integrating responsibility and sustainability data into daily operations and development processes, companies can leverage the development plans they have formulated as part of their practical responsible business practices, promoting profitable, realistic sustainability activities through these analyses. Companies updated their sustainability expertise and business strategies from a sustainable development perspective, the significance of which can be assessed, for example, through self-assessments and sustainability reporting. According to the feedback received, companies will continue to develop sustainability and responsibility in practice, driven by strategic stakeholder cooperation and a commitment to competitiveness. In the future, those who participated in the project will be able to take responsibility factors into account in everyday operations and tie them into the company's operations and future. Subjective experiences related to the business environment were restrictions, and stakeholders' demands might differ

depending on the business environment. The participants felt that linking responsibility and sustainable development to the company's operations made it easier to understand the topic and identify opportunities as part of practical business.

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Make backups or pay!

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Abstract: Cybersecurity company Sophos has published its fifth annual report on The state of Ransomware 2025. Their research investigated the impact of ransomware attacks on different companies. The average amount of money that companies paid for getting their data back was 1 million dollars, so it is clear that cybercrime in general is a huge „business field” and ransomware attacks in particular are very serious problems for companies. Defence technologies evolve quite quickly but 100% security level cannot be reached. In this paper I investigate how data backups can help minimizing the losses in case of a successful ransomware attack – or any other problem resulting in data loss.

Keywords: ransomware, data backup

1 Introduction

What can cause data loss? A lot of things. Only a few examples will follow:

A natural catastrophe such as an earthquake (see Fukushima), fire, firemen's activity in case of fire, pipe burst. Sudden cut-off of electricity. Secondary effect of a lightning strike.

Wear and tear of hardware elements, especially hard drives (including solid state disks). Even in ideal working conditions the hardware elements will go wrong after a while.

Someone can steal a computer not because of the data stored in it but for the price of the hardware.

A computer can be stolen in order to get the data stored in it. It can be, in some circumstances, the simplest way to acquire the data.

Human errors. Someone can erase the data accidentally. Or as a form of revenge. There may be software errors as well.

Malicious software, commonly called as “viruses”. [5] Among them quite a new “star”: ransomware. [6] ItFdu

is a special kind of malware (malicious software) that uses encryption in the victim's system making the data unavailable for regular use. If the victim pays a ransom s/he will be sent the decryption key. At least theoretically. There are cases when the victims didn't get the decryption key and there is at least one case when the encryption process had a bug and it was mathematically impossible to decrypt, even having the would-be decryption key.

Ransomware is quite a new branch in the field of cybercrime. Sophos antivirus company ran an annual research in 2024 (as well), asking some thousand companies in all over the world about their ransomware related experiences. [7] They found that 59% of companies experienced ransomware attacks in the previous year. More than half of them agreed to pay the ransom. "The average (median) payment has increased 5-fold over the last year, from \$400,000 to \$2 million" [7] depending on the size of the company. According to Ákos Bódis a Hungarian cybersecurity expert [8] the ransomware business could be the third largest economy in the world, after that of the US and China.

It is because there are some very serious differences between the traditional, analogue, physical world and the virtual world. In this situation the most important difference is that in the virtual world both the crime and the payment can be done anonymously and without useful tracks because of the special attributes of the virtual world. [9] No need to be physically on the spot as Ronald Biggs had to be on the Glasgow-London mail train. And no need to meet in person to get the ransom or find out so special tricks as D. B. Cooper had to do on the Portland-Seattle flight. As a result, cybercrime means significantly less risk than traditional crime, generally speaking.

2 Value of data

IT-systems of everyday life consists of, at least, three main parts. First one is the hardware. It is of little value, even if it has its price that can be even very high. In other words, if hardware goes wrong, gets too old, disappears, etc., you can buy new hardware. It is only a matter of (enough) money.

The second component is the software. It is very similar to the hardware from this point of view. Has its price but if you have the licence for the software you use you can re-install it. Or, if you don't have any licences for it, you can get it from the same source you got it previously. From the practical point of view the result is the same: after having bought new hardware and re-install your software you have your working environment again. Let it be either a single home computer or quite a big server farm of an enterprise. Software is also a matter of money only.

The third component is the data you store in your computer system. It is the most valuable part of your system. A possible classification of data is the following: you can divide your data into two groups.

The first one is the so-called reproducible data while the other group is the irreproducible data. It means that if you have lost your, e.g., accounting data (supposing you are a company) or you have lost, e.g., your just finished final thesis two days before the deadline just before printing it out then you are in trouble. Good news that this kind of trouble can be managed and you can reproduce your data. You can get the original bills and invoices so you can enter the accounting data for the second time into your newly-built system and then you can continue the regular everyday work. Obviously, this process needs human resources, time, etc., in one word: money, but finally you can restore the original state of your working system and you can continue your work in the normal way. If you are a university student you'll have to re-write your final thesis and you can apply for the final exam – maybe a semester later, but you'll realize how easier to write the final thesis for the second time. To minimize the cost of such an event you want to develop your own business continuity plan, BCP (see, e.g., ISO 22301:2019). In some cases you can try some data recovery services, such as the Hungarian Kürt Zrt.

As for the second group of data, the irreproducible data, the situation is more complex. There is no way to get your irreproducible data if you have lost it. If you have lost your incoming orders (as a company running a webshop) before processing it, you will never have or make the possibility to get them once again. Or if you have lost the meteorological data you measure hourly in different points of the Carpathian Basin, there are no possibilities to re-measure them. It is also impossible to re-take the family photos of the last summer holiday.

So the irreproducible data needs to be protected the most.

What can you do? Or a better question: what do you have to do? At least three important things: a) make backups, b) protect it, c) use your mind (if there is any).

The most important activity you are supposed to do is to make data backups. If you have the appropriate backups then you will have the possibility to restore your data after any disasters. Secondly, if you have a well-planned (and done) backup process then you can start to work on not needing the backups. In this step you'll set up a firewall, anti-virus software, intrusion detection system [1], intrusion prevention system [2] or whatever you think important and can do.

The third element in preventing data loss is the human factor: Notice every unusual circumstance. A good example of this from the near past is the case of Andres Freund, Last year (in 2024) a computer user, working for Microsoft as a developer, installed a new, beta Debian. He found that to set up an ssh connection became longer than it was previously. The difference was about half a second, just a man can perceive. And he started to investigate what the reason was and found a serious backdoor that could have been a real world-wide catastrophe if he hadn't discovered it. [3] [4]

3 Data backups

The most important task is to have a proper backup procedure either you are a big company or a private person. If you have backups then the second most important task is to develop and use defending procedures at the physical, administrative and algorithmic levels of defence. The first one means that you are supposed to close the door of the server room (don't leave it on the seat of your car) and provide your equipment with the optimal or, at least, satisfactory working conditions. The second means you must have the appropriate regulations about who and when can enter the server room at all. While the third means that you can, and have to, use the computers themselves in the defence, firewalls, etc.

Data backups belong to the third level, mainly. But without the appropriate regulations (second level) it will not be satisfactory. How to plan, organize a good-enough backup system? The main parameters are: the amount of data, how quickly the data changes, how much time we have for recovery (after a data loss event). In following part of this paper I'll investigate two simple procedures that can be used in general, office like situations including, of course, the "home office".

The "general office situation" means that the total amount of data is a few gigabytes on a single office computer, consisting of, mainly, docx, xlsx, pptx, pdf files, there maybe saved html files and some jpg pictures. E.g. my workspace, as an associate professor in IT, contains about 20 thousand files (of which about 4.600 is created or last modified this year) in about 6 gigabytes, after many years of work.

The very basic backup is to copy all the files onto another storage equipment and put that equipment far from the original computer. There are more effective ways of backing up, let's see two of them: the incremental and the differential backups.

3.1 Incremental backup

In the first step a full backup must be performed, obviously. Then in regular intervals, e.g. daily, you have to copy the files that have been modified or created since the previous backup was created. If the backups are done at the end of the office hours then, e.g., the backup created on Tuesday evening will contain all the files that were created or modified on Tuesday (supposing that on Monday evening the previous step was accomplished correctly).

It is quite fast, needs little time and not much storage space as one incremental backup step will contain a small number of files. On the other hand, if you have to restore your workspace after a data loss, you'll have to copy back the full backup created in the first step and then each incremental steps in the appropriate order overwriting possibly existing files. So the backup process needs little time while the restoring process needs significantly more. If any of the backup files is corrupted or disappeared then your data after that link or point may not be correctly restored.

3.2 Differential backup

The first step is the same, you must make a full copy of your workspace. Then in the subsequent steps you copy all the files that differ from the ones in the full backup of the first step. It means that as time goes on the backup packages will grow bigger and bigger. For example you create the first, full backup on Monday evening. The Tuesday backup package will contain all the files that were created or modified on Tuesday. The Wednesday backup package will contain all the files that were created or modified on Tuesday and Wednesday and so on.

In this case the backups need (a bit) more and more time and storage space every day. But after a data loss the restoring process is simpler and quicker: you'll have to copy back the first (full) backup package and the very last one. The risk of a broken backup chain is significantly less than in case of the incremental backup. Looking at the fact that in case of general and regular office-style circumstances a full data loss does not happen frequently (luckily), in such circumstances I'd prefer the first, incremental, method. In case of both methods you'll have the earlier versions of a file on which you were working for long, so it can give additional possibilities against logical or human errors.

3.3 Backup tools

In case of Windows there is the xcopy command you can use in a Command window – yes, Windows has a command line!

In case of Linux you have more possibilities: one is mirroring tool rsync but it needs a remote computer to copy to and quite a good network connection. And you can do the incremental/differential backups with find and tar and gzip.

On Windows the xcopy command [10] can do the job. Each file in a Windows filesystem has a so-called archive bit. It is set by the operating system every time when the given file has changed (including its creation as well). The xcopy command can use this archive bit to decide whether a given file should be copied or not.

The command “xcopy /?” displays its help. The way it should be started is “xcopy xcopy <Source> <Destination> <options>”. Among its options the very basics ones are: /s copies directories and subdirectories, unless they're empty. The /e option copies all subdirectories, even if they're empty and can be used together with /s. The /a option copies only *source* files that have their archive file attributes set. /a doesn't modify the archive file attribute of the source file. The /m Copies *source* files that have their archive file attributes set. Unlike /a, /m turns off archive file attributes in the files that are specified in the source.

In addition to the `xcopy` command there is an `attrib` command that can be used to set (or clear) the archive bits, recursively, if needed.

So we have the possibility to make either incremental or differential backups with the `/a` or the `/m` option.

In case of Linux there are other possibilities as we have no archive bits. Without an archive bit we can use the timestamps of the files. When starting the backup in the first step we create a file to preserve the date and time of the given backup. Every file that is newer than this should be copied, recursively, next time. If we do incremental backup the timestamp of this file should be set at the beginning of each process while in case of differential backup we set the timestamp only in the first step (the full backup).

Then we can use the `find` command [11] to find the necessary files. This `find` command has the option “-newer timestamp-file”. Based on this option we can find those files (with the `find` command:) that are newer and so they must be backed up. We can redirect the output of the `find` command to a text file and then we can use the `tar` command [12] to put these files one by one into a single `tgz` file (something like a zip file). Then, or even in real time, we can send this package to another place, either to a remote computer via the network or to a local storage device what can be even (simplest case) a usb stick.

4 Cloud

The so called “cloud” is someone else's computer. Using the cloud can be very comfortable for a company, especially when different users must access the same files regularly, so keeping them in one place that everyone can access simplifies the organisation of the work very much. The question is: In case of using a “cloud” as a service provided by someone else, should we do our own backups or should it be enough for us that we have a contract with them containing guarantees for the availability of the cloud and keeping our files safe?

I would say that guarantees are nice but to have one (more) copy of my data in my hands is nicer. As the old rule says: In case of digital data one copy is not a copy, two copies is half a copy, three copies is one copy (and security starts at four copies). It may sound sort of funny but there is an old Hungarian wise saying: “Better safe than sorry”.

Conclusions

In the virtual or digital world the digital data is a (the?) real value so we are supposed to keep our data safe. As there are no storage devices that could give us a guarantee for being able to retrieve our data from it, not even for a limited time period, we have to make backup copies if we want a higher level of security. It has become more important since ransomware attacks started.

There are a lot of aspects of developing a backup process for a given person or company, in this paper I gave an outline for this, supposing an average, general office like environment in general, and also in particular both for Windows and Linux.

One should keep in mind that the price and security level function is similar to the function $f(x) = -1/x + 100\%$. It never, never reaches the 100% level but it can go quite close to it. The higher security level you want the much higher investment you have to do.

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I have to say a big “Thank you, professor!” to Mr. Ervin Szűcs, my late professor at the Department of General Technics who let me use the supercomputer of the department when I was a first year student. Without that, most probably, I haven't become an IT guy. That supercomputer was an IBM compatible XT with 640 kB RAM and a 10 MB hard drive and was the only one our department had at those times.

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Technical fundamentals and application prospects of self-driving vehicles: from sensors to civil and military mobility

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Abstract: Self-driving vehicles represent one of today's most innovative areas of technological development, transforming transportation, logistics, and warfare simultaneously. The aim of this study is to present the technical content of autonomous systems, with a particular focus on development milestones, key technologies, and the strategies of leading industry players. We analyze in detail the role of sensors—LiDAR, radar, cameras, and ultrasound—as well as the importance of sensor fusion and artificial intelligence-driven decision-making. We also discuss navigation and localization solutions, which are essential for safe transportation. In the field of civilian use, the main areas of focus are improving transport safety, sustainable urban mobility, and logistics optimization, while military applications are opening up new horizons in the areas of logistics convoys, reconnaissance systems, and autonomous combat vehicles. The analysis emphasizes that the future success of autonomous technologies will be determined by the combined development of technical advances, regulatory frameworks, and public trust.

Keywords: autonomous vehicles, sensor reliability, artificial intelligence, cybersecurity, technical challenges

1 Introduction

Autonomous vehicles (AVs) represent one of the most significant technological developments of our time, fundamentally reshaping the future of transportation and mobility. In recent decades, the increasingly close integration of the automotive industry and information technology has led to the creation of complex systems capable of continuously sensing the traffic environment, processing data, and autonomously making decisions and controlling vehicles. The technical background behind self-driving technologies is multidisciplinary: robotics, artificial intelligence, sensor technology, remote sensing, and communication networks are all key elements in the operation of these systems (Thrun, 2010; Anderson et al., 2016). Several factors are driving these developments. On the one hand, improving road safety and reducing the number of road accidents is a priority, as a significant proportion of road accidents

are attributable to human error (Fagnant & Kockelman, 2015). On the other hand, increasing mobility needs, social expectations for sustainable transport, and the need to improve logistical efficiency are also key factors. In addition, technology is playing an increasingly important role not only in civilian transport, but also in military and industrial applications, for example in the form of autonomous logistics convoys or reconnaissance vehicles (Lin, 2016). The aim of this study is to analyze the technical content and development of self-driving vehicles, with a particular focus on key technologies, manufacturer strategies, the functioning of sensor systems, and civil and military applications. The structure of the material first reviews the milestones and technological levels of development, then analyzes the technical components—sensors, navigation systems, and artificial intelligence. This is followed by a presentation of the global manufacturing environment and industry players, and the study concludes with a summary of the opportunities and challenges presented by civilian and military applications. The aim of the analysis presented is to provide a comprehensive picture of how self-driving vehicles will shape the future of transportation and what technical, economic, and social issues will arise during their introduction..

2 Development and technological milestones

The development of self-driving vehicles is the result of decades of research and industrial effort, closely linking robotics, computer science, and transportation engineering. Initial experiments began in the 1980s, when research teams at Carnegie Mellon University and Mercedes-Benz developed prototypes that were capable of limited lane tracking and obstacle avoidance (Dickmanns & Zapp, 1987). These early systems still relied heavily on simplified models of the environment and a combination of image processing and rule-based algorithms. Development gained new momentum in the early 2000s with the DARPA Grand Challenge competitions, which aimed to encourage the development of autonomous vehicle applications in the field. In the first competition in 2004, none of the vehicles were able to complete the course, but even then, the integration of sensors, navigation, and control algorithms represented a significant step forward (Thrun et al., 2006). During the 2005 and 2007 competitions, the participating vehicles were already capable of traveling tens of kilometers in complex environments, demonstrating the reality of autonomous driving. Starting in 2010, development focused on the automation levels (0–5) defined by the SAE, which provide a uniform framework for evaluating the technology. Level 2 systems (partial automation) were already capable of controlling acceleration and steering simultaneously, but driver supervision was still required. Level 3 (conditional automation) and above allow the vehicle to drive autonomously under certain conditions, while level 5 represents full autonomy without human intervention (SAE International, 2021). Among the industry milestones, the Google/Waymo project plays a prominent role, as it was one of the first companies to demonstrate the feasibility of

self-driving systems in a real-world environment, having already covered millions of kilometers in road conditions (Waymo, 2020).

Similarly significant is Tesla's Autopilot system, which has made Level 2 driver assistance features widely available, although its operation is accompanied by safety concerns and legal disputes (Favarò et al., 2017). Uber and other mobility service providers have also conducted significant experiments in the field of robotaxi technologies, which, however, have raised serious ethical and regulatory challenges. Another key element of development is the evolution of the regulatory and legal environment. While experimental permits and legal frameworks for self-driving tests have gradually emerged in the United States and Europe, China and other Asian countries are encouraging development through large-scale government programs (Liu & Xu, 2021). However, issues of standardization, data security, and liability remain unresolved. Future developments will be determined by deeper integration of artificial intelligence and machine learning. Self-driving systems are increasingly capable of making real-time decisions based on the processing of large data sets and adapting to changes in the traffic environment in an adaptive manner. Cloud-based infrastructure, 5G communications, and vehicle-to-everything (V2X) technologies will also play a key role in the coming decade, as they enable cooperation between vehicles and the optimization of traffic systems (Campolo et al., 2017). The development of self-driving vehicles has progressed in recent decades from prototype-level experiments to widely tested systems that are partially available on the commercial market. These technological milestones not only signal advances in technical capabilities, but also indicate that autonomous transport is moving closer to mass adoption, although the timing of this remains dependent on a number of technological, regulatory, and societal factors.

The development of autonomous vehicles (AVs) has made spectacular progress in recent years, both in academia and industry. This development covers several key areas: end-to-end architectures, environment perception and representation, path planning and decision-making algorithms, and simulation and validation methods. Foundation models and systems based on historical prediction are also becoming increasingly prominent. The following summary provides an overview of the most important technical achievements and challenges based on ten studies published between 2023 and 2025.

The goal of end-to-end (E2E) systems is to guide the flow of information from raw sensor data to control commands through a single learning architecture. This significantly reduces the number of interface errors arising from modular designs and enables global optimization. Lan and Hao's (2023) review shows how this is being applied by industry players such as Tesla FSD V12 and Momenta, as well as in academic research. Common features include the use of Bird's Eye View (BEV) representation and occupancy networks, which transform data from various sensors (camera, lidar, radar) into a unified map. The main challenges are handling rare traffic situations, minimizing computational requirements, and verifying safety. Research presented at CVPR 2025 further expanded the capabilities of end-to-end models by integrating historical sensor data. This enables the system to not only infer from the

current environment, but also take into account past dynamics, resulting in more accurate predictions and more natural path planning (Bridging Past and Future, 2025).

The development of environmental representation is key to the safe operation of AVs. 2D BEV models are effective but limited in their handling of vertical structures. 3D occupancy perception offers a new approach that models the environment in voxelized space. Xu et al. (2024) have detailed how information fusion techniques can be applied to combine camera, lidar, and radar data. Advanced architectures, such as 3D convolutional networks and transformer modules, enable the system to create a probabilistic map of the environment's occupancy. Challenges include high computational requirements, annotation costs, and sensor limitations (e.g., poor lighting conditions, occlusion).

Collaborative perception has opened up new perspectives in environmental sensing. Technologies such as Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and Vehicle-to-Everything (V2X) communication enable vehicles to exchange data with each other and with infrastructure to detect obstacles that their own sensors cannot see. The 2024 review highlights the importance of open datasets and benchmarks, which are essential for developing and comparing algorithms (Collaborative Perception Datasets, 2024).

In the field of path planning, in addition to classic algorithms such as Dijkstra and A*, sampling-based methods such as RRT and PRM, as well as machine learning-based approaches, have gained greater prominence. According to a 2024 review by Reda et al. (2024), the goal of newer systems is to integrate path planning with motion prediction so that vehicles can anticipate the behavior of other road users (Path Planning Algorithms, 2024). Waymo's ModeSeq system, developed for the 2024 challenge, presents a multimodal approach to motion prediction. Using a transformer-based architecture, it generates multiple possible future trajectories whose diversity and accuracy exceed those of traditional RNN-based models. This capability is particularly useful in congested urban environments, where multiple future scenarios must be considered (ModeSeq, 2024). Closely related to this, the BehaviorGPT model simulates the behavior of traffic agents using generative methods. This allows realistic scenarios to be created in which autonomous systems can be stress tested. Traffic simulation is thus not only a validation tool, but also an active area of research (BehaviorGPT, 2024).

Decision-making in autonomous vehicles is developing along two main lines. Rule-based and optimization-based methods, such as Markov Decision Processes or search algorithms, are explainable and deterministic, but have limited adaptability to dynamic environments. Data-driven methods, such as imitation and reinforcement learning, are more flexible but require large amounts of data and extensive simulation environments. The 2023 review article highlights that the three levels of decision-making—strategic, tactical, and operational—require different approaches (Zhang, Li, & Wang, 2023). According to a more detailed summary from 2025, the future lies in hybrid systems that combine the transparency of rule-based methods with the adaptability of data-driven models (Hu, Zhang, Li, & Zhao, 2025). Validation and verification remain a

key issue: systems must be tested not only in average situations, but also in rare, safety-critical scenarios.

The use of foundation models in autonomous vehicle research promises a paradigm shift. These large-scale, multimodal models are capable of integrating knowledge from different sources, such as sensor data, traffic situations, and simulations. According to the review study, the strength of foundation models lies in their adaptability and generalization, which enable systems to operate robustly even in new environments (Foundation Models in Autonomous Driving, 2025). The biggest challenges are computational resource requirements, lack of transparency, and safety verification. It is clear that self-driving vehicle technology is on an integrated development path. End-to-end systems simplify the architecture, 3D occupancy perception offers more accurate environmental models, the integration of path planning and motion prediction improves safety, while collaborative perception and generative models open up new possibilities for validation. In decision-making, hybrid approaches and foundation models are the future, capable of balancing explainability, flexibility, and robustness. The main challenges in the coming years will be scalability, meeting real-time requirements, and compliance with safety standards.

3 Technical content and key technologies

The operation of self-driving vehicles is based on complex hardware and software architectures that enable continuous environmental sensing, data processing, and real-time decision-making. The most important components of the system include sensors, algorithms for sensor fusion and data processing, navigation and localization solutions, and control systems based on artificial intelligence. The goal of self-driving vehicle sensor systems is to cover the entire spectrum of the traffic environment. One of the most important sensor types is LiDAR (Light Detection and Ranging), which uses laser beams to create a highly accurate, three-dimensional map of the vehicle's surroundings. The advantage of LiDAR is its high resolution and reliable distance measurement, but its disadvantages are its high cost and sensitivity to adverse weather conditions (Svoboda et al., 2016, Ghraizi, 2023). Radar technology is used to determine distance and speed and is particularly reliable in poor visibility conditions. Ultrasonic sensors provide support at short range, primarily in parking and low-speed maneuvering situations. Cameras provide visual information that is key to object recognition, traffic sign and signal identification, and lane marking detection. The disadvantage of cameras is that they require high computing power and are sensitive to changes in lighting conditions (Janai et al., 2020).

Autonomous driving systems do not rely on a single sensor, but use a sensor fusion approach that combines data from different sensors to increase redundancy and reliability. Sensor fusion allows the vehicle to create a more accurate and robust environmental model, reducing errors caused by the weaknesses of individual sensors (Khaleghi et al., 2013). Based on the processed data, the system is able to detect and

track objects and predict their movement, which is essential for safe maneuvering. Accurate positioning is one of the biggest challenges for self-driving vehicles. Global positioning systems (GPS) alone do not provide sufficient accuracy, so a combination of HD (high-definition) maps and real-time localization algorithms (e.g., SLAM – simultaneous localization and mapping) is required. Such systems are capable of determining the position of a vehicle with centimeter accuracy, while continuously updating the map of the environment to reflect changing traffic and infrastructure conditions (Levinson et al., 2007).

The central element of autonomous driving systems is the application of artificial intelligence (AI) and machine learning. Neural networks, especially convolutional neural networks (CNNs), play a key role in image processing, object recognition, and interpreting traffic situations (Grigorescu et al., 2020). Decision-making modules are responsible for planning responses to different traffic situations, including route planning, obstacle avoidance, and safe vehicle control. Real-time control requires high-performance hardware platforms. Manufacturers such as Nvidia and Intel/Mobileye have developed special chip architectures capable of processing large amounts of sensor data and running AI algorithms in real time. This hardware-software integration enables the responsiveness and safe operation of self-driving vehicles. It can be concluded that the technological background of self-driving vehicles is extremely complex and relies on the close cooperation of various sensors, algorithms, and control systems. The direction of development is determined by the ever-deeper integration of artificial intelligence, the development of sensor fusion solutions, and the application of high-precision navigation systems. The synergy of the technical components ensures that self-driving vehicles will be able to operate safely and efficiently in both civil and military transport systems in the future.

4 Manufacturers and industry players

The development of self-driving vehicles has led to global industry competition, in which car manufacturers, technology companies, and startups all play a decisive role. The market is characterized by the fact that traditional automotive companies are constantly expanding their research and development activities, while players in the technology sector are shaping the competitive environment with new approaches and innovative software solutions. Among traditional car manufacturers, Tesla stands out with its Autopilot and Full Self-Driving (FSD) systems, which provide the most widely available, commercially available partial self-driving functions (Shladover, 2018). Although Tesla's system represents level 2 automation according to the SAE classification, the company is seeking to gradually expand the range of functions through continuous software updates. Among European manufacturers, Mercedes-Benz was the first to receive official approval in Germany in 2021 for the introduction of a Level 3 autonomous driving system (Drive Pilot) on public roads, which can be considered a milestone in terms of legal and technological recognition (Mercedes-Benz, 2021). Volkswagen and BMW are also pursuing ambitious development

programs focused on shared mobility and robotaxi services. In the US market, General Motors is developing self-driving vehicles through its subsidiary Cruise, which are already in test operation in several major cities.

In the technology sector, Waymo is considered one of the market's biggest innovators. The company, which spun off from Google, was among the first to complete millions of kilometers of autonomous test drives and currently operates robotaxi services in the United States (Waymo, 2020). The Baidu Apollo program plays a similar role in China, with extensive government support and strategic partnerships (Liu & Xu, 2021). Although Apple officially releases little information, it has been actively testing its self-driving systems for years, which are linked to the company's development program known as Project Titan. Nvidia and Intel/Mobileye tend to offer hardware- and software-based solutions, such as high-performance AI processors and driver assistance algorithms, which enable OEMs to integrate autonomous systems (Gavriliu et al., 2020). Startups play a key role in the global technology ecosystem. Aurora, Zoox (acquired by Amazon), and Nuro are developing specialized self-driving solutions that focus specifically on freight and urban logistics. These companies are often more agile and risk-taking than large corporations, enabling them to respond more quickly to new market demands. Players involved in the development of autonomous vehicles have also emerged in the military sector. The US Department of Defense (DoD) is funding several projects targeting self-driving logistics convoys and reconnaissance vehicles (Defense Science Board, 2016). Israeli and European companies are also actively working on autonomous vehicles for military use, such as unmanned combat vehicles. The industry is highly globalized, with American and Chinese players dominating, but Europe and Japan are also active participants. The competition is not only technological, but also has economic and geopolitical significance, as self-driving vehicles are strategic pillars of the mobility infrastructure of the future. According to market forecasts, the global market for self-driving vehicles could reach hundreds of billions of dollars by 2030 (MarketsandMarkets, 2020). This industry is not only transforming car manufacturing, but also logistics, urban transport, the insurance sector, and the regulatory environment.

5 Possibilities and uses (civilian and military)

The development of self-driving vehicles is not only a technological innovation, but also offers comprehensive social, economic, and safety opportunities. Autonomous systems, which are used in both civilian transportation and military applications, have the potential to transform mobility structures, improve efficiency, and increase safety. At the same time, both areas present serious challenges and risks that affect the widespread introduction of the technology.

One of the greatest promises of self-driving vehicles is improved road safety. More than 90% of road accidents are attributable to human error, so autonomous systems have the potential to significantly reduce the number of deaths and injuries (National

Highway Traffic Safety Administration [NHTSA], 2017). Self-driving vehicles are capable of making the right decisions in situations where human drivers would hesitate or make mistakes, thanks to the rapid response times provided by sensors and algorithms. In urban transport, autonomous systems can contribute to the development of mobility services, for example through the introduction of robotaxi fleets and self-driving buses. These solutions can reduce traffic congestion, increase the utilization of transport infrastructure, and support sustainable urban mobility concepts (Litman, 2020). Self-driving logistics vehicles can also revolutionize the freight transport sector by optimizing route planning, reducing labor requirements, and improving energy efficiency. Their environmental potential is also of particular importance. Autonomous vehicles can optimize the entire transport network, reducing fuel consumption and pollutant emissions. For example, convoys controlled by self-driving systems can use "platooning" technology, in which multiple vehicles drive closely behind each other, minimizing air resistance and increasing energy efficiency (Tsugawa, 2016). In military applications, the development of autonomous vehicles is of strategic importance. One of the most important areas is the automation of logistics convoys, which can significantly reduce human casualties on dangerous supply routes. Autonomous convoys are capable of operating in a coordinated manner with minimal human supervision, while increasing the mobility and supply security of the army (Gow & Carpenter, 2016). Reconnaissance and surveillance vehicles also play an important role in modern warfare. Autonomous systems are capable of real-time data collection in hostile environments, reducing the risk to human soldiers. In addition, the development of unmanned combat vehicles and drones is intensifying, and their deployment on the battlefield could provide a strategic advantage (Singer, 2009).

At the same time, military use raises serious ethical and legal dilemmas. The use of autonomous weapon systems—especially when they make decisions without human intervention—is the subject of significant international debate, as it is unclear who would be responsible for any damage or violations of the laws of war (Lin, 2016). Particular attention must be paid to cybersecurity in both civilian and military applications, as the network vulnerability of autonomous systems can pose a serious security risk. A successful cyberattack can cause not only material damage but also endanger human lives (Petit & Shladover, 2015). Social acceptance, regulatory frameworks, and liability issues pose further challenges, all of which determine the pace of widespread adoption of the technology. The civilian use of self-driving vehicles can contribute to increased traffic safety, sustainable mobility, and more efficient logistics processes. In the military sphere, autonomous systems offer strategic advantages in logistics and reconnaissance, but also raise new ethical and security dilemmas. A common feature of civilian and military applications is that the technological advantages can only be realized if appropriate responses to security, regulatory, and social challenges are found.

Conclusions

Over the past few decades, self-driving vehicle technology has evolved from the level of research prototypes to the threshold of commercial application. In this study, we

reviewed the milestones of this development, from early experiments and DARPA competitions to modern, large-scale robotaxi services. The automation levels defined by SAE provide a framework for measuring technological advancement and also indicate further directions for research and development (SAE International, 2021). An examination of the technical content revealed that the operation of autonomous vehicles is based on various sensor systems, sensor fusion, high-precision localization, and artificial intelligence-based decision-making. These components work closely together to ensure that the vehicle is able to perceive, interpret, and respond in real time in complex traffic environments. Analysis of industry players has shown that traditional car manufacturers, technology companies, and agile startups are all present in the global competition. Tesla, Mercedes-Benz, Waymo, and other key players are pursuing different strategies, but all of them aim to introduce safe, commercial-grade autonomous systems. The market has enormous growth potential, which also has significant economic and geopolitical implications (MarketsandMarkets, 2020). Civilian applications include improving transport safety, optimizing urban mobility, and improving the efficiency of logistics processes. Military applications also hold great potential, particularly in the areas of logistics and reconnaissance. At the same time, regulatory, ethical, and safety challenges are of paramount importance in both spheres and must be addressed in order to achieve widespread social acceptance (Lin, 2016). Overall, self-driving vehicles are not just a technological novelty, but are fundamentally transforming the future of mobility, transport safety, environmental protection, and warfare. In the coming decades, the key to success will be the harmonious balance between technological developments, regulatory frameworks, and social trust.

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