Chapter 5

Industry 4.0 in Resource Efficient and Cleaner Production: A case study from the food sector in Jordan

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Abstract: The concentration of CO_2 in the atmosphere has reached 400ppm, a higher level than at any time in the history. As clearly referred at IPCC reports, human activity has been behind this extraordinary increase. Transition to a net-zero at industries is one of the crucial measures to meet the international commitments regarding climate change and thus keep the global warming below the 1.5C° limit. Resource Efficient and Cleaner Production (RECP) provides practical example of de-coupling between economic growth from environmental degradation and thus support achieving the net zero transition. In that context, RECP has been applied at 12 industries in Jordan resulted in saving of over 1.6 million Jordanian Dollars (JOD) annually, 22,181 MWh/yr of energy; 63,844 m^3/yr of water; 404 tons/yr of raw material and reduction of 8,086 tons/yr of CO_2 emissions. Integrating industry 4.0 tools into RECP has been shown to be very efficient as the industries have become able to monitor and validate all saving data on real time bases and optimize using natural resources accordingly. Saving measures and performance evaluation were linked with IoT sensors and Blockchain at one food industry in Jordan and found to be accurate and very helpful to assess input-output outflow within the industry boundary. Employing IoT with blockchain to facilitate collecting data related to RECP at industry level can be a great advantage to RECP and help in monitoring carbon footprint accurately. It is recommended to scale up RECP-industry 4.0 model to other industries and leverage this experience to expedite transition to circular economy.

Key words: Resource Efficient and Cleaner Production (RECP), Industry 4.0, IoT sensors, Blockchain, Circular Economy

5.1 Background

The rapid population growth and improvement in life standards have led to a large volume of natural resources being extracted. Resource extraction increased from almost 27 billion tons in 1970 to 92 billion tons in 2017 (IRP, 2020). In recent decades, material extraction has become more concentrated in upper-middle-income countries, while the higher-income countries maintain the highest material footprint of 27 tons per capita representing 13 times of the low-income group (IRP, 2019). Over the past two decades, there has been a rapid acceleration in the extraction and processing of natural resources, which is responsible for over 90% of biodiversity loss, water stress, and approximately 50% of the impacts related to climate change (UNEP, 2019). Therefore, decoupling is needed to stop environmental degradation while attaining economic growth (Jackson, 2009). The environmental impact of the industrial sector shows a continuous increase, which has coincided with continuous change in environmental strategies moving from passive to proactive through a cleaner production strategy (Ramos et al., 2020).

Industrial food processing plants are characterized by significant water, energy, and material consumption. The agri-food sector is a major consumer of energy and water, where almost 30% of the world's energy is consumed within agri-food systems (IRENA and FAO, 2021). The agri-food industry relies on energy for various purposes, including machinery and equipment operation, transportation, processing, refrigeration, and packaging. Energy consumption can vary across different stages of the food supply chain, from farm operations to processing plants and distribution networks. Water consumption in the agri-food industry is substantial due to various activities such as irrigation for crop production, livestock watering, and food processing. It is estimated that globally, the agri-food sector accounts for around 70% of freshwater withdrawals. This includes both direct waters use in agricultural activities and indirect water use in food processing and production. The global average water footprint for sugar crops for example is estimated at 200 m3/ton, fruits 1000 m3/ton, cereals 1600 m3/ton, and oil crops 2400 m3/ton (Mekonnen and Hoekstra, 2011). Nevertheless, exact figures for water and energy consumption in the agri-food industry vary by region and specific practices.

Companies themselves play a major role in optimizing the resources being used in production. It is estimated that 40-50% of raw materials of food delivered to companies are rejected for quality issues (Stefan et al., 2004). Once a food processing plant is operational and its products are available in the market, one of the most efficient methods to mitigate environmental impacts is by implementing the Resource Efficient and Cleaner Production approach (RECP). RECP is an enterprise-level approach that focuses on resource optimization, minimizing environmental pollution, and fostering sustainable industrial development (UNIDO, 2010). By implementing RECP, the generation of waste is reduced, and the full potential of raw materials is maximized. The RECP is basically underpinned by the concept of de-coupling of economic growth from environmental degradation and is part of the global efforts to enhance the transition to the circular economy. In essence, cleaner production is a key component of the Circular Economy, as it helps to ensure that materials and products are produced in a way that is sustainable and environmentally responsible. By integrating cleaner production practices with the Circular Economy model, companies can work towards a more sustainable and circular economic model, which can ultimately help to promote economic, social, and environmental sustainability. There are multiple methods to do the RECP such as SCORE – Sustaining competitive and responsible enterprises; TEST – Transfer of Environmentally Sound Technology and PREMA — Profitable resource-efficient management (STENUM, 2021), each of which has different features, yet with one goal, which is minimizing the ecological footprint of the products while improving the financial performance of the industries.

5.2 RECP demonstration in Jordan

The RECP was demonstrated in Jordan during the period from 2015 to 2018 within the SwitchMed project. The SwitchMed initiative was a regional project funded by the European Union (EU) and implemented by the United Nations Industrial Development Organization (UNIDO) (Medwave, 2022). In Jordan, the project applied the TEST method for implementing RECP in the targeted industries. TEST was organically developed by UNIDO and is underlined by the concept of Material Flow Cost Accounting (MFCA) and supported by the material and energy flow information system (MED TEST, 2012). By embracing the TEST methodology, businesses can implement sustainable production models, leading to a range of benefits. These include enhanced productivity, lowered operational expenses, improved product quality, optimized investments, reduced costs associated with environmental compliance, minimized environmental impact, expanded opportunities to enter new market segments, resilient supply chain, and stronger relationships with stakeholders.

As part of the SwitchMed project, the TEST methodology has been successfully demonstrated in 12 companies in the food and beverage sector in Jordan during the period 2015-2018. Initial assessments (IAs) were conducted to assess each company’s environmental, energy, and economic potentials as well as the management motivation. TEST is implemented on the basis of the Plan-Do-Check-Act (PDCA) cycle as shown in Figure 1 below. RECP teams from external consultants and internal companies’ staff (finance, production, operation, quality assurance, maintenance) were established at each targeted industry and together demonstrated the TEST assessment. Figure 5.1 below shows an overview of the TEST methodology that was applied to the 12 industries in Jordan.

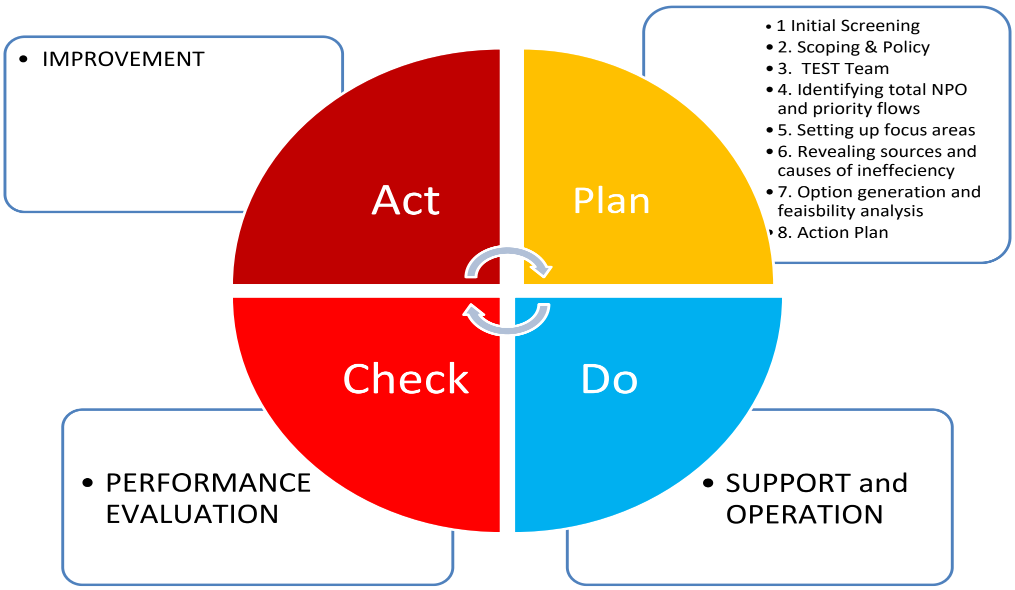


Figure 5.1: Overview of the TEST approach

Source: UNIDO TEST Tool Kit, available at: https://www.test-toolkit.eu/

Applying the TEST method has led to the discovery of significant savings potential in 12 food and beverage plants that participated in the program. These savings include an annual energy reduction of 22,181 MWh, water savings of 63,844 m3 per year, 404 tons per year of raw material savings, a decrease of 8,086 tons per year in CO2 emissions, and the avoidance of 83 tons per year of solid waste going to landfills (SwitchMed Magazine, 2018). In total, the RECP team identified 214 resource efficiency measures across the 12 demonstration companies. Out of these, 161 measures (approximately 75% of the total) were approved by company management and included in the companies' plans for action. Most of these interventions had a Pay Back Period (PBP) of less than six months (48%), with an investment requirement of less than 7,000 JOD (9,300 Euros). Furthermore, around 23% of the measures were categorized as good housekeeping measures, highlighting their high profitability. Table 5.1 provides examples of RECP measures identified in two medium-sized food industries (with fewer than 100 employees) through the TEST approach, along with their respective payback periods.

Table 5.1: Saving opportunities at two food industries that applied TEST methodology

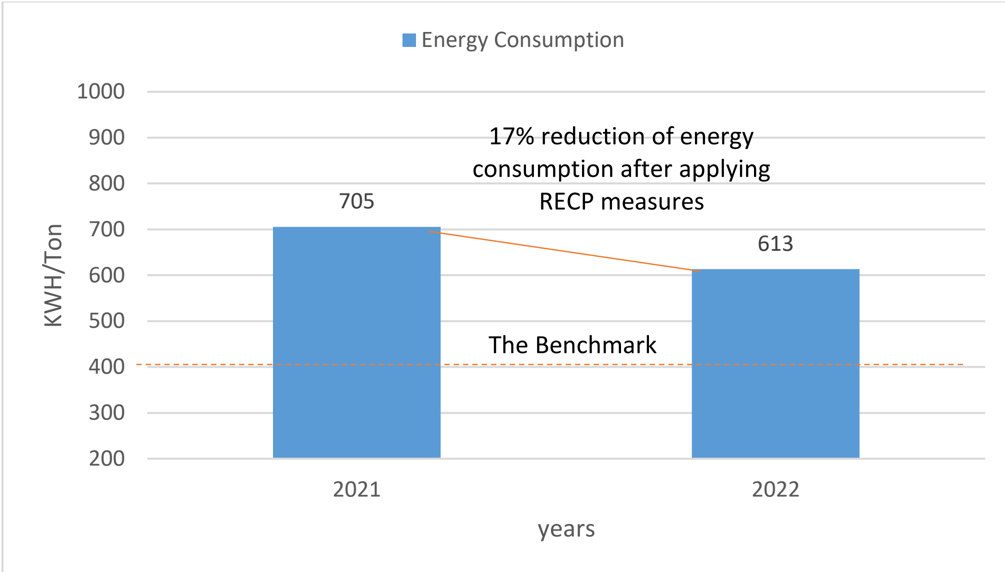
Measures/saving opportunities	**Main financial figures**			**Saving in resources per year**		
	Investment	**Savings/ Yr**	**PBP/Yr**	**Materials and Water**	**Energy MwH**	**Pollution reduction**
Carbonated soft drinks industry						
Optimization of Clean in Place (CIP)	€6,600	€27,755	0.2	8,160 m^3 Water	276	Total: 1,190tons CO_2
Water conservation	€10,133	€225,060	0.1	18,210 m^3 Water,	886	

				329.6 t & 40.5 m^3 Raw materials		35.9tons Solid waste 677 kg BOD_5 1,221 kg COD 40,000 m^3 Recycled wastewater
Raw materials savings	€2,933	€20,744	0.1	12 m^3 Water 4 t of sugar & 1.3 t of preform as Raw materials	1	
Lighting and cooling systems	€23,860	€108,555	0.2	-	866	
Steam and compressed air systems	€62,240	€71,245	0.9	-	616	
Dairy industry						
Reducing the losses of raw materials and water	€1,002,030	€196,220	5.1	7.1 tons Raw materials 7,505 m^3 Water	205.2	Total: 209 tons CO_2 4.0 tons Solid waste
Heat recovery and conservation	€13,730	€10,140	1.4	262 m^3 Water	179.4	
Lighting and compressed air	€2,030	€2,610	0.8	-	24.2	
Cooling system	€30,330	€18,210	1.7	-	168.7	

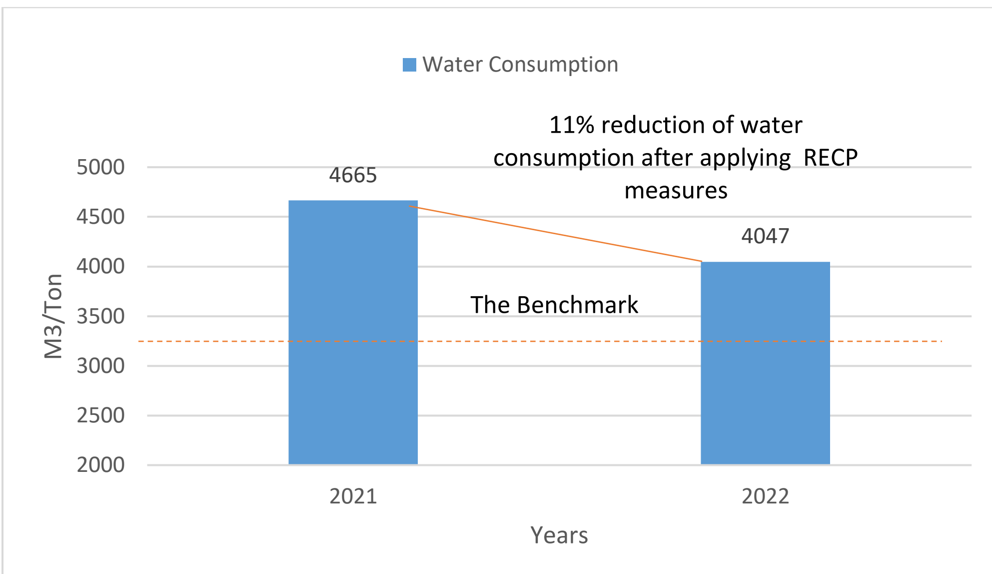
Source: SwitchMed Magazine 2018, available at https://www.unido.org/sites/default/files/files/2020-01/SwitchMed%20Magazine%20-%20Jordan.pdf

Interestingly, most of the saving measures identified during the TEST were implemented by the companies themselves. After a year of implementation, a performance evaluation was conducted considering the benchmark and information system that was set from the very beginning to control inefficiencies that are related to resource productivity. The effective implementation of RECP options led to significant performance enhancements toward reaching the established benchmark. Figure 5.2 below shows the performance of the water and energy-saving measures implemented in one of the Food Companies producing mainly frankfurter, frozen burgers, mortadella, breaded meats, and meatballs. The energy measures such as using LED lights, installing sub-meters to refrigerators and compressors, fixing all steam leakages, and optimizing the temperature of refrigerators, were able to reduce energy consumption by 17%. Likewise, water measures such as the reuse of treated wastewater, monitoring water supply, and installing water-sub-meters, achieved an 11% drop in water consumption.

However, the regular collection of data and coordination among different departments for effective data management at the company level posed challenges in validating the RECP measures. This highlights the significance of integrating Industry 4.0 tools into the RECP concept.



(a)



(b)

Figure 5.2 (a & b): Reduction in energy and water consumption at one Food Company after applying RECP measures

5.3 Applying Industry 4.0 in RECP

Industry 4.0 is a term used to describe the ongoing automation and digitalization of industrial processes. It encompasses technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), Big Data Analytics, and Advanced Robotics. Industry 4.0 is characterized by the ability to connect machines, devices, and people in real-time, allowing for greater efficiency, productivity, and customization in manufacturing processes (Noor et al. 2018).

As already mentioned, the Agri-food industry consumes a vast amount of resources (materials, energy, and water) and generates a huge amount of food waste. It has been shown above that RECP offers significant benefits to the industries including cost saving and providing more sustainable food products. However, industries that apply RECP are struggling to digitally audit, monitor, verify, and store savings in resources, which in many cases hinder the continuous improvement of resources management at a company level. Therefore, by collecting and analysing RECP data at the industry level in real time, better management decisions can be made to improve resource efficiency (Jagtap et al. 2021). Therefore, the integration of Industry 4.0 technologies into cleaner production processes has the potential to significantly reduce the environmental impact of manufacturing. By utilizing real-time data and advanced analytics, companies can identify areas of inefficiency and waste in their production processes and optimize them for greater efficiency and reduced environmental impact. So Industry 4.0 is seen as a key driver of sustainable development in manufacturing, and an important step towards a more circular and sustainable economy. For example, the use of advanced sensors and machine learning algorithms can help manufacturers optimize energy consumption, reduce waste, and improve the use of raw materials.

The utilization of Industry 4.0 tools in the food industry has recently gained significant attention and has been discussed in various academic literature. Noor et al. (2018) examined the practical implementation of Industry 4.0 technologies in the food processing sector. They identified nine key technological advancements that are driving Industry 4.0 and explored their application areas within the food industry. These areas included intelligent manufacturing, food safety, training, and marketing. The authors emphasized the crucial role of Industry 4.0 in enhancing resource efficiency, reducing costs, expanding market access, improving customer satisfaction, implementing systematic management practices, ensuring enhanced food safety, and promoting transparency. Kumar (2020) further highlights the importance of Industry 4.0 technologies in addressing the challenges faced by the food sector. In their study, Jagtap et al. (2021) introduced a framework that leverages the Internet of Things (IoT) for monitoring food waste generation, as well as the consumption of energy and water in the food industry. The framework comprises three key stages: defining the necessary datasets for tracking food waste, water usage, and energy consumption; designing an IoT system to monitor and enhance resource efficiency in waste generation and consumption; and developing a decision support tool to model and design strategies for managing food waste, water usage, and energy consumption. The research paper establishes a conceptual basis for employing IoT-based technologies to monitor waste generation, water usage, and energy consumption on an industrial scale, with the aim of providing real-time information to factory management through intuitive dashboards.

The application of blockchain technology for food traceability has also received considerable attention in the existing literature. In their study, Prince et al. (2020) proposed a hybrid model that combines recurrent neural networks (RNN) algorithms with Internet of Things (IoT) and blockchain technologies to forecast the supply and demand of food. The model utilizes long short-term memory (LSTM) and gated recurrent units (GRU) as prediction models while employing the Genetic Algorithm (GA) optimization to optimize the hybrid model's parameters. The research offers supply chain practitioners the opportunity to leverage cutting-edge technologies and develop policies based on the predictions generated by advanced deep learning (ADL) techniques.

Furthermore, Kayikci et al. (2019) and Casino et al. (2021) extensively explored the potential implementation opportunities and obstacles associated with adopting blockchain technology in the food supply chain, considering the aspects of people, process, performance, and technology. The authors highlighted that blockchain technology has the capability to address trust-related concerns within the supply chain by facilitating secure data storage with inherent privacy and management features. Joseph (2019) focused on the application of blockchain technology to ensure that the results of milk analysis remain unaltered and tamper-proof, thereby preventing unauthorized modifications by any involved stakeholders, notably regulatory agencies. This implementation was crucial for enhancing protection not only for consumers but also for producers, safeguarding their reputation in case of any downstream food-related issues and ultimately bolstering the security of the food supply chain.

As part of the ongoing work by the Royal Scientific Society (RSS) of Jordan with the Royal Academy of Engineering (RAE), UK, a novel framework has been introduced to improve RECP management and data collection at the food industry level. The framework links the IoT systems and blockchain together and was installed at the chicken breast production line in one food industry in Jordan. The main goal was to monitor product quality, environmental conditions, production process, power consumption, waste generation, and any up-normal events. The structure of the digital framework includes, 1. System typology where communication channels and type of data are programmed, 2. Data sources by which multiple data sources are identified i.e., weighing sensor, metal sensor, temperature sensor for output meat, power consumption sensors, and shock freeze temperature sensor, 3. IoT gateways are where the data are collected to IoT gateways and then connected to the blockchain (Figure 5.3).

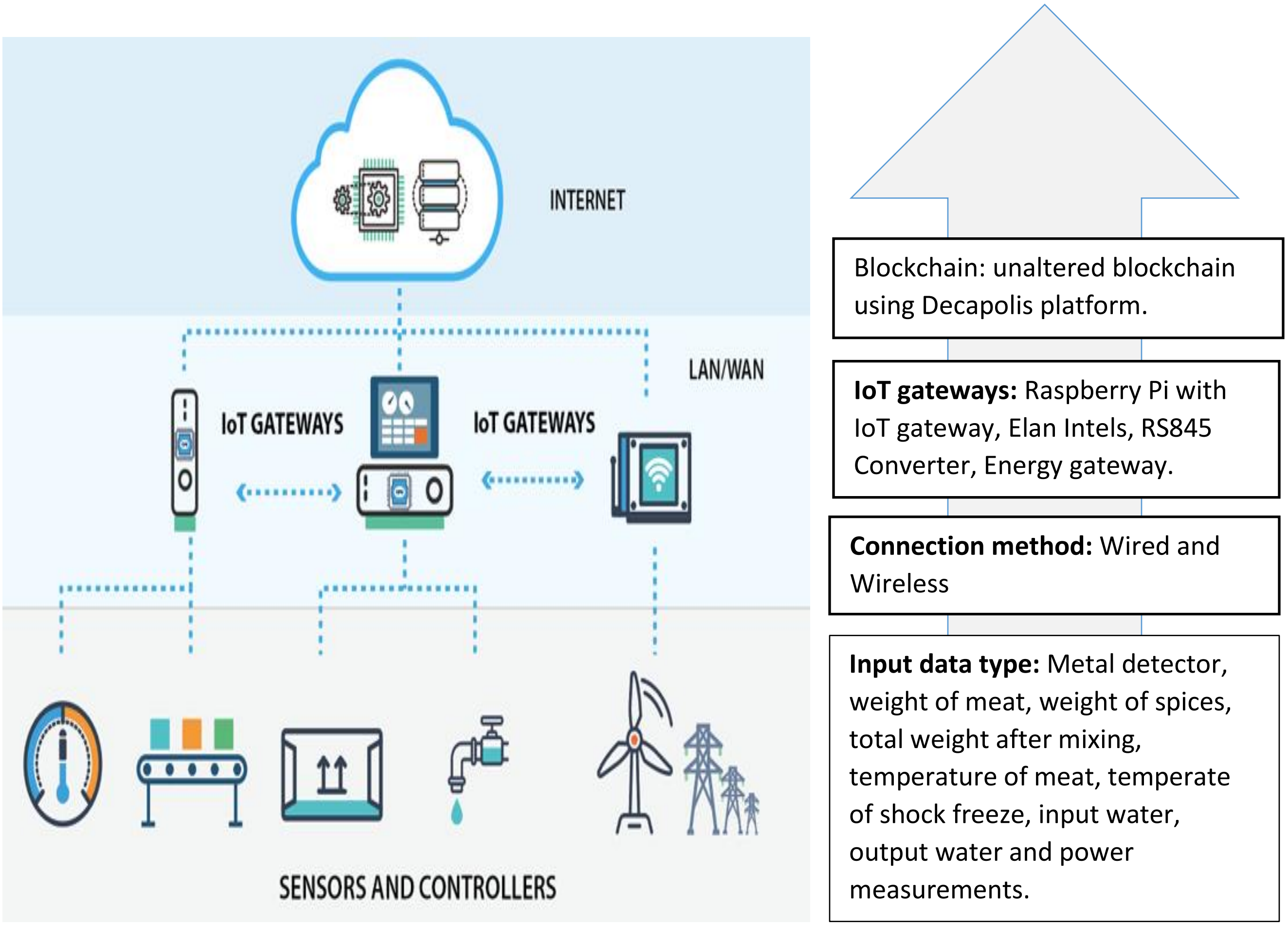


Figure 5.3: The framework of IoT and Blockchain that was applied at chicken breast production line at one food industry in Jordan

The data streams of energy, raw materials, water consumption, and factory emission data are then stored in an unalterable way on the Decapolis Blockchain platform. Decapolis is a Jordanian technology enterprise that provides traceability solutions for food safety using Blockchain technology (https://www.decapolis.io/). This will allow the company to assess the costs of production and provide a basis for making production processes more efficient more accurately. Figure 5.4 below shows an example of how data is being displayed via web and mobile phone on a real-time basis and provides actual data on natural resources consumption based on the RECP assessment.

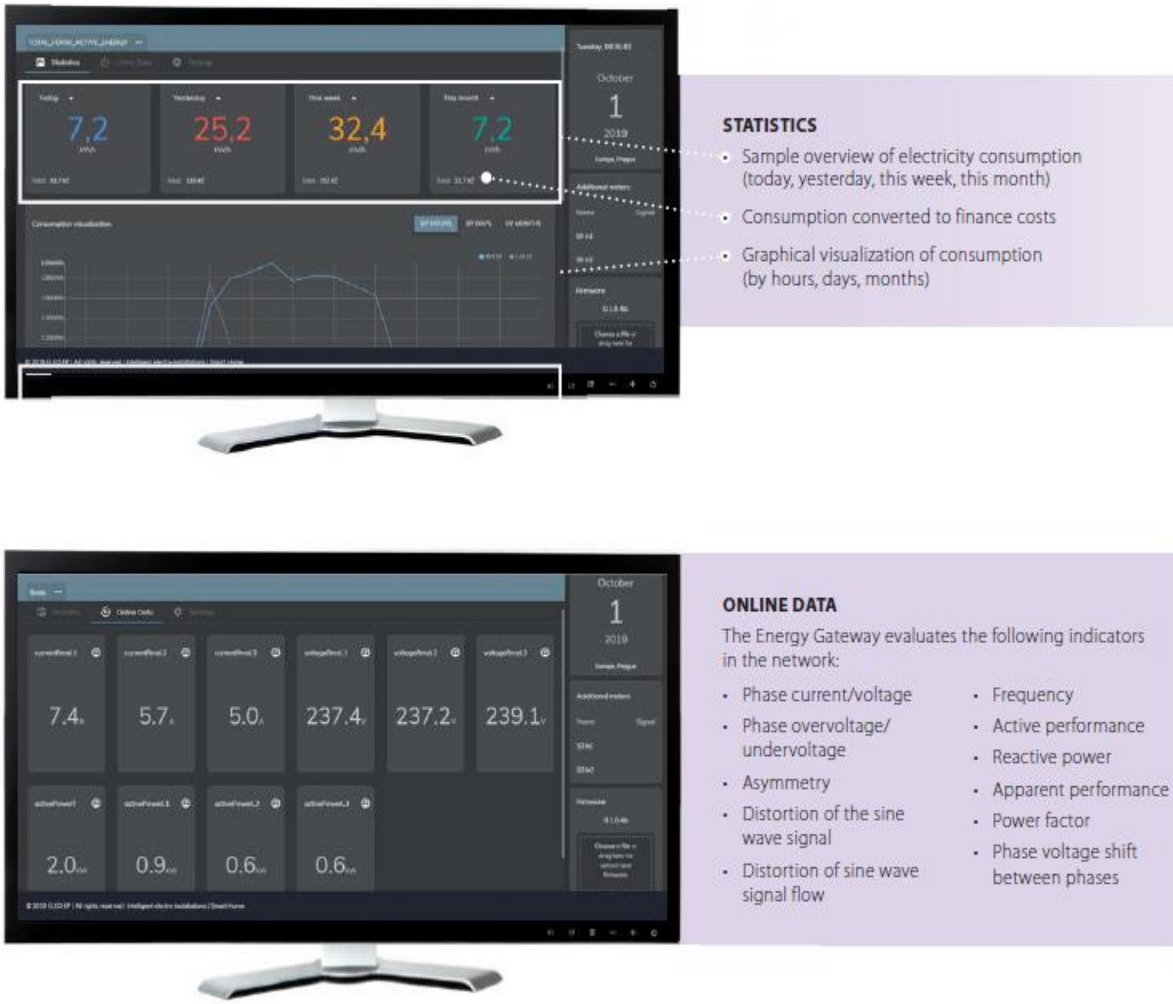


Figure 5.4: Data display on real-time bases and stored at a blockchain software

This allows the company to have an RECP database that stores transaction-based records, continually recording all completed transactions in a block of data. More importantly, this process is important to facilitate the transition to a circular economy to ensure regulatory compliance in various sectors for better processing across focal points and other actors in supply chains.

4. Conclusions

The following conclusions can be drawn from this paper:

1. There are various approaches to implementing RECP, one out of which is TEST, which was demonstrated in 12 industries in Jordan and was behind in saving 22,181 MWh/yr; 63,844 m^3/yr of water and 404 tons/yr of raw material.
2. The RECP measures ranged from simple measures (quick wins) to high investment measures. Yet, most of the measures were economically feasible with a pay-back period falling between 2 months to 5 years.

3. Integration of Industry 4.0 tools into RECP has improved the ability of RECP teams in industries to take timely decisions in terms of natural resource consumption. More importantly, it improved transparency, and greatly reduced inefficient manual performance evaluation and costs.
4. Blockchain will help to track data and more accurately monitor carbon footprint and ensure integrity. Linking blockchain with RECP would also establish a reliable relationship between actors without a mediator, which will significantly support the transition toward a circular economy.

The study shows the tremendous potential the integration of RECP approach and Industry 4.0 provides to industries in helping them to improve operational efficiency while also reducing the environmental impact. We therefore recommend rolling out integrated RECP with 4.0 to other industries across all sectors.

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