ENVIRONMENTAL IMPACT OF INTELLIGENT TRANSPORTATION SCHEDULE FOR ELECTRIC VEHICLE IN AL-SOKHNA PORT

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1. ABSTRACT: Intelligent transportation systems and the use of electric vehicles in ports can have a positive impact on the environment by reducing emissions and promoting sustainability. It is important to note that the specific environmental impact would depend on various factors, including the scale of implementation, the efficiency of the charging infrastructure, and the overall energy mix used for electricity generation in the region. This paper examines the environmental effects of optimizing the transportation scheduling of Electric Vehicles (EVs) at Al-Sokhna port. It employs the Discrete Water Cycle Optimization Algorithm (DWCOA) to establish the best schedule, capacity, and routes for the EVs. The mathematical modelling of the system is detailed, covering its objective function, boundary values, conditions, limitations, and constraints. The optimization algorithm and system are implemented using Matlab. The study, focused on Al-Sokhna port, reveals several significant outcomes, including a reduction in emissions, decreased noise pollution, improved energy efficiency, enhanced integration of renewable energy, and a shift in transportation modes.

2. INTRODUCTION

The global transportation sector has witnessed a steady shift towards sustainable practices in recent years [1]-[2]. With the growing concerns over climate change and the need to reduce greenhouse gas emissions, the adoption of Electric Vehicles (EVs) has emerged as a promising solution [3]. In particular, the integration of Intelligent Transportation Systems (ITS) and renewable resources with EVs has the potential to revolutionize the way goods are transported, enhancing efficiency and minimizing environmental impact. EVs are increasingly being used as transportation aids in ports, contributing to cleaner air by minimizing harmful emissions from conventional diesel engines [4]-[5]. The Environmental Protection Agency's (EPA) Diesel Emissions Reduction Act (DERA) Program provides grants and rebates for the replacement of heavy-duty diesel vehicles with electric alternatives. This initiative encompasses funding for commercial charging, public transportation charging, and the acquisition of vehicles, particularly focusing on retrofitting heavy-duty diesel vehicles, engines, and equipment with advanced low-emission technologies, including electric vehicles (EVs) and their associated charging infrastructure [6].

The future of transportation is electric, with ports being equipped to charge one or more vehicles simultaneously [1],[7]. Charging stations are being installed at major public transportation terminals, including ports for instance, some ports have Level 3 Direct Current Fast Chargers (DCFC) that can accept a direct connection to Tesla vehicles without the use of an adapter. Other stations are equipped with a Combined Charging System (CCS) and CHArge de MOve (CHAdeMO) option connector for charging [7]-[8]. Several companies are committing to the use of electric vehicles. For example, Amazon has rolled out over 3,000 Electric Delivery Vehicles (EDVs) as part of its commitment to bring 100,000 EDVs to the road by 2030. Similarly, Trane Technologies is committing to transitioning 100 percent of its global fleet of more than 8,000 vehicles, including service vans and trucks, to all-EVs by 2030 [8]-[9].

Efforts are also being made to ensure that EV charging stations are accessible to and usable by people with disabilities. The Joint Office of Energy and Transportation (JOET) has hosted webinars on designing for accessible EV charging stations, sharing information and discussing accessibility guidelines and best practices in the design and construction of EV charging stations [9].

Al-Sokhna Port, located on the Red Sea coast of Egypt, is a crucial hub for international trade [10]-[12]. As the demand for goods transportation continues to rise, it is imperative to explore sustainable alternatives that can mitigate the negative environmental consequences associated with traditional transportation methods. The implementation of an intelligent transportation schedule with renewable electricity resources for EVs in Al-Sokhna Port presents a unique opportunity to address these challenges effectively. It has the potential to revolutionize goods transportation while significantly reducing the environmental impact [13]-[14]. By leveraging advanced technologies, such as artificial intelligence, data analytics, and real-time communication systems, an intelligent transportation schedule can optimize vehicle charging and operating time, minimize congestion, and reduce energy consumption. Consequently, this can contribute to a significant reduction in greenhouse gas emissions, air pollution, and noise pollution within the port vicinity.

This paper aims to analyze the environmental impact of implementing an intelligent transportation schedule for EVs integrated with charging system from renewable resources as Photovoltaic (PV) and wind energy in Al-Sokhna Port. To assess the environmental impact, this study will utilize a comprehensive approach that combines data analysis, modeling, and simulation techniques. By examining factors such as vehicle utilization, energy consumption, and emissions, the potential benefits of implementing an intelligent transportation schedule for EVs can be qualified. Additionally, the study will consider the economic feasibility of such a system, evaluating the cost-effectiveness and potential return on investment. Furthermore, this paper will examine the challenges and barriers to implementing an intelligent transportation schedule for EVs in Al-Sokhna Port. Factors such as infrastructure requirements, charging station availability, and stakeholder collaboration will be addressed to provide a holistic understanding of the feasibility and potential limitations of the proposed system. The findings of this study will provide insights and recommendations for policymakers, port authorities, and stakeholders involved in the transportation sector, fostering a transition towards a more sustainable future. This paper is presented through six main sections in addition to the abstract and references. These sections are introduction, electric vehicles as transportation aids in ports, discrete water cycle optimization algorithm, the port of Al-Sokhna, system simulation, results and discussion, and conclusion.

3. ELECTRIC VEHICLES AS TRANSPORTATION AIDS IN PORTS

Electric vehicles are playing an increasingly important role in ports and other transportation hubs. They are not only reducing harmful emissions but also paving the way for a cleaner, more sustainable future. The mathematical modelling of electric vehicle transportation scheduling in ports is a complex task that involves various aspects of logistics, energy efficiency, and automation. This process is crucial for improving freight efficiency and promoting energy saving in the port environment. It involves understanding the driving forces of an EV, the energy consumption of these vehicles in large-scale transportation networks, and the infrastructure required to support their operation [8]-[9]. Mathematical modeling plays a crucial role in the adoption and optimization of EVs. It helps in understanding the performance, safety, and reliability of batteries, which are key to making EVs safer, cheaper, more efficient, and able to last longer between charges. For instance, researchers have developed mathematical models to improve the lifetime of lithium-ion batteries used in EVs. These models have resulted in globally-used software tools for modeling prototypes of new batteries, significantly reducing the time and cost for companies developing electric vehicles [9]. Energy consumption is a significant factor in the operation of EVs. Recent literature contains energy modeling techniques for EV energy consumption in large-scale transportation networks. These models provide insights into the energy requirements of EVs in different scenarios, which is crucial for planning and optimizing their use in ports. The infrastructure to support EVs is another critical aspect of their use in ports. This includes charging stations, which are necessary for the operation of EVs.

3.1 The mathematical modelling of the electric vehicles in ports

Mathematical models can be used to assign optimal delivery tasks to EVs, improving efficiency and reducing operational costs. A scalable energy modeling framework is often used for electric vehicles in regional transportation, which can be applied to the tasks of scheduling container transportation. Mathematical modelling also involves optimization techniques. Furthermore, a heuristic algorithm can be used to overcome the excessive computational time needed for solving the mathematical model.

The mathematical model can incorporate priority rules, objectives and constraints for EV scheduling integrated with renewable energy charging resources. This can help in integrated location selection, number of used EV, time, duration of transportation and scheduling problems for inland transportation. The modelling of EVs transportation scheduling in ports involves a combination of logistics technology, energy modeling, optimization techniques, and intermodal transportation principles as given in Eq. (1).

$$Fit.Fn.(NEV, tst, D, P) = Fit.Fn._{technical}(NEV, tst, D, P) + Fit.Fn._{economic}(NEV, tst, D, P) + Fit.Fn._{environmental}(NEV, tst, D, P) \quad (1)$$

Where: *Fit.Fn.* is the overall fitness function of the system. It consists of three parts which are $Fit.Fn._{technical}$, $Fit.Fn._{economic}$, and $Fit.Fn._{environmental}$. $Fit.Fn._{technical}$ represents the technical part of the fitness function. $Fit.Fn._{economic}$ demonstrates the economic part while $Fit.Fn._{environmental}$ illustrates the environmental impact of the system in which the penalty for CO_2 emission is considered. *NEV* is the number of used EVs, *tst* is the starting time for operation, *D* is the duration of transportation stroke based on the EV speed and torque, and *P* is the EV consumed power.

3.2 System charging constraints

The eco-friendly EVs scheduling in ports must obey different categories of technical, maintenance and operating constraints. Port operation schedule is one of the important constraints that affects the economic target dramatically. Some technical constraints such as speed-stroke distance relation, EVs power and energy consumption should be considered. The system charging constraints are illustrated in Eq. (2) and (3).

$$P_{ch}(t) \leq P_{chmax} \quad \text{and} \quad P_{disch}(t) \leq P_{dischmax} \quad (2)$$

$$\sum_{t=1}^{T} P_{disch}(t) = \sum_{t=1}^{T} P_{ch}(t) * \eta_{bat} \quad (3)$$

Where: $P_{ch}(t)$ and $P_{disch}(t)$ are EV battery both charging and discharging power as function of time respectively, wh ile the maximum charging and discharging power limits are P_{chmax} and $P_{dischmax}$ respectively. η_{bat} is the battery efficiency.

4. DISCRETE WATER CYCLE OPTIMIZATION ALGORITHM

The Discrete Water Cycle Optimization Algorithm (DWCOA) is a novel and promising optimization technique inspired by the water cycle process in nature [15]-[21]. This algorithm presents a unique approach to solving optimization problems in discrete domains, offering potential applications in various fields, including engineering, computer science, and operations research.

The DWCOA mimics the movement of water in the hydrological cycle, consisting of condensation, precipitation, evaporation, and runoff as shown in Figure 1. Each of these stages in the water cycle is metaphorically translated into mathematical operations within the algorithm [15]-[16]. This approach allows the DWCOA to efficiently explore the search space and find optimal solutions for discrete optimization problems. The algorithm's effectiveness lies in its ability to strike a balance between exploration and exploitation. It achieves this by simulating the natural water cycle's ability to adapt to changing conditions. The DWCOA employs a diverse set of operators, including droplet formation, droplet movement, evaporation, and runoff, to navigate the search space intelligently.

In addition to its adaptability, the DWCOA exhibits robustness against various problem complexities [17]-[21]. It can handle discrete optimization problems with multiple objectives, constraints, and non-linear functions. This versatility makes it well-suited for real-world applications, such as resource allocation, scheduling, and network optimization.

Empirical studies have shown promising results for the DWCOA, outperforming traditional optimization algorithms in terms of solution quality and convergence speed. Furthermore, its simplicity and ease of implementation make it accessible to researchers and practitioners alike.

Despite its notable advantages, the DWCOA is not without challenges. Fine-tuning the algorithm's parameters may require careful consideration, and its performance may vary depending on the problem characteristics. Further research and experimentation are needed to explore its full potential and optimize its performance.

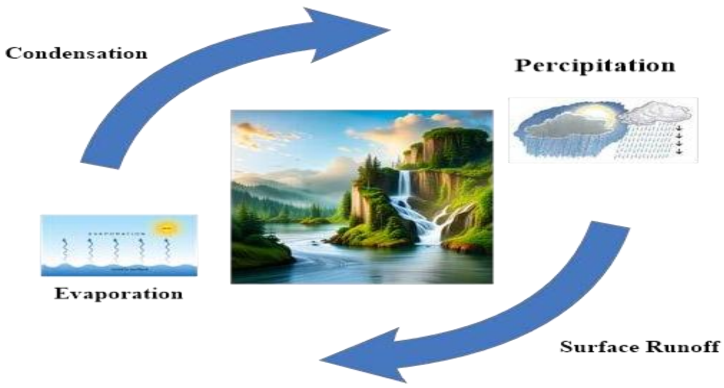

Figure 1: Water Cycle Optimization (WCO) nature-inspiration

The DWCOA algorithm starts similarly to WCA in which an initial streams (i.e., population) is generated randomly between Upper Boundaries (UB) and Lower Boundaries (LB) according to Eq. (4) [19].

$$X_{New\ stream}(ti) = round\ (LB + rand * (UB - LB)) \tag{4}$$

An initial matrix of individuals of size $N_p \times N$ is created as illustrated by Eq. (5) [20]-[21]. Therefore, the randomly generated matrix X which is given as follows:

$$Population_{Total} = \begin{bmatrix} S \\ R_1 \\ . \\ . \\ S_{Nsr+1} \\ . \\ S_{Np} \end{bmatrix} = \begin{bmatrix} X_{11} & X_{21} & X_{31} & \dots & X_{N1} \\ X_{12} & X_{22} & X_{32} & \dots & X_{N2} \\ . & . & . & \dots & . \\ . & . & . & \dots & . \\ . & . & . & \dots & . \\ . & . & . & \dots & . \\ X_{1Np} & X_{2Np} & X_{3Np} & \dots & X_{NNp} \end{bmatrix} \quad (5)$$

Where,
N: is the number of design variables,
R: is the rivers, *and* S: is the streams.
N_p: is the total population size.
The cost function value depends on the intensity of flow for each stream and is calculated as follows:

$$Costi = f\,(x_1^{i}, x_2^{i}, \qquad , x_N^{i}\,) \quad i = 1, 2, 3,..., N_p \quad (6)$$

The designated streams for sea and each river are calculated using the following equations:

$$C_n = Cost_n - Cost_{Nsr+1} \qquad n=1,2,3,....N_{sr} \quad (7)$$

$$NS_n = round\{|C_n/\Sigma\, C_n| * N_{Streams}\}, \qquad n=1,2,3,....Nsr \quad (8)$$

Where,
NS_n: represents the number of streams that flow into specific rivers or the sea.
There are N_p individuals, of which N_{sr-1} are designated as rivers and one is identified as the sea [19]-[21].

The updated positions for the streams and rivers can be expressed using the following equations.

$$X_{Str}(ti+1) = X_{Str}(ti) + rand * C * (X_{Riv}(ti) - X_{Str}(ti)) \quad (9)$$

$$X_{Str}(ti+1) = X_{Str}(ti) + rand * C * (X_{Sea}(ti) - X_{Str}(ti)) \quad (10)$$

$$X_{Riv}(ti+1) = X_{Riv}(ti) + rand * C * (X_{Sea}(ti) - X_{Riv}(ti)) \quad (11)$$

Where,
rand: is a random number between [0, 1]. Equations (9) and (10) are regarded as the updating equations for the new positions of streams that flow to rivers and the sea, respectively. Where, Eq. (11) represents the updated equation for the rivers that pour into the sea. Notations with a vector sign indicate vector values, while the remaining notations and parameters are considered as scalar values. The flowchart of DWCOA is depicted in Figure 2.

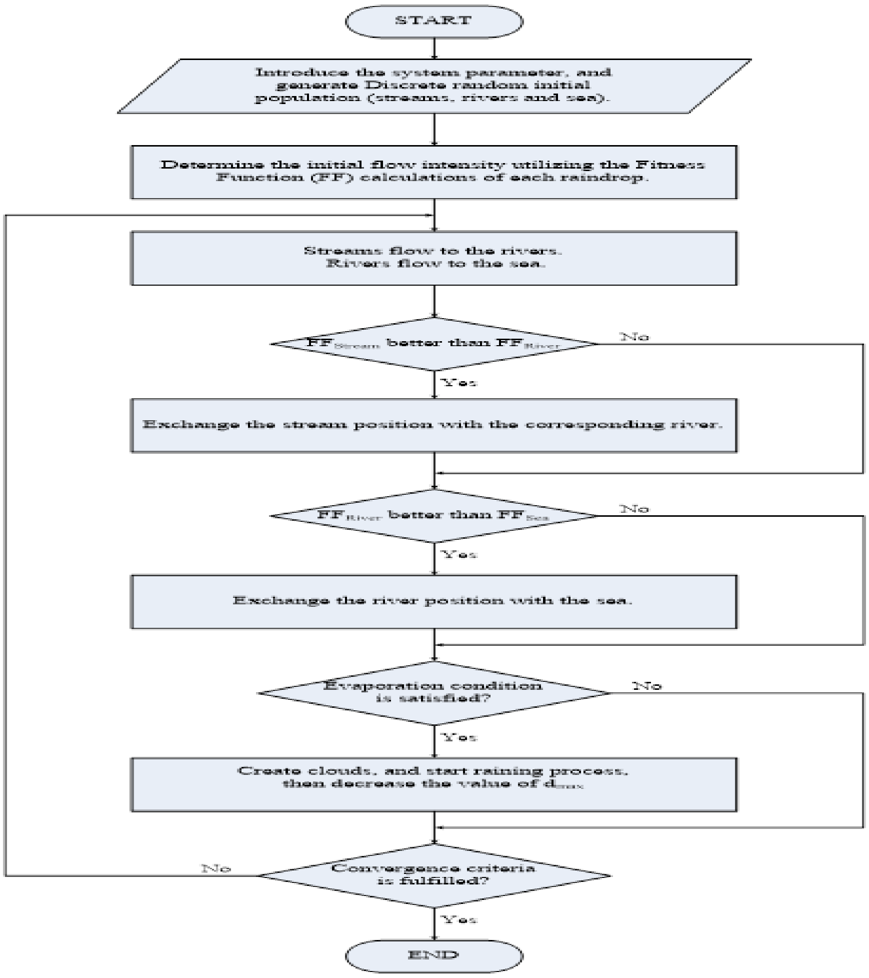

Figure 2: Discrete Water Cycle Optimization Algorithm (DWCOA) flowchart

5. THE PORT OF AL-SOKHNA

The Red Sea geographical location plays a significant role in the major trade routes connecting Europe and the Far East. This strategic positioning is intended to enhance exports and capture a larger share of both regional and international markets for container handling, transshipment, and transient services. The Red Sea is an essential segment of the maritime Silk Road, extending from the Chinese coast to Singapore, Kuala Lumpur, Colombo in Sri Lanka, the southern tip of India, Mombasa in East Africa, Djibouti, and through the Suez Canal to the Mediterranean. This route serves as a vital trade link between Asia and Europe, with approximately 19,000 vessels navigating daily, accounting for 12% of global trade and 30% of global container traffic.

Al-Sokhna Port is a significant seaport located on the east coast of the Gulf of Suez, approximately 50 km south of the Suez Canal as illustrated in Figure 3. It is situated on the Red Sea's western shore, making it an attractive option for container lines moving cargo from Asia to Egypt, as they can avoid the expensive Suez Canal transit dues [10]-[13]. The port is also strategically positioned, being just about 90 minutes away from Cairo, the Egyptian capital and the main production and consumption center in Egypt.

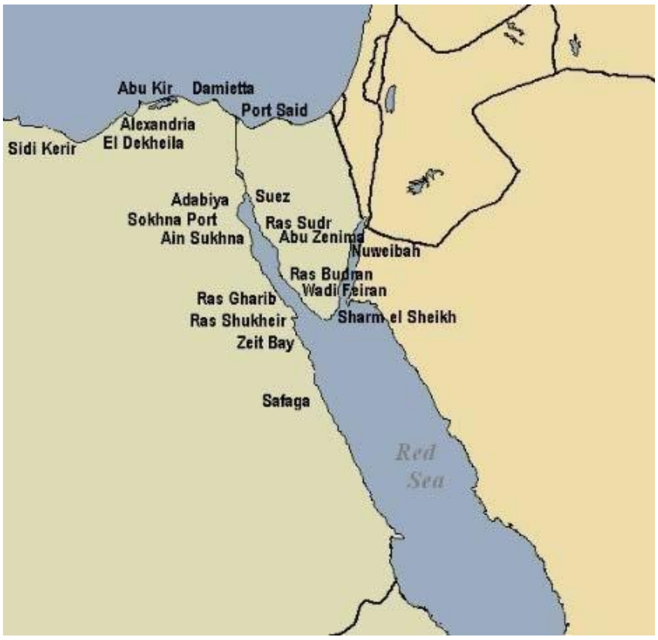

Figure 3: Al-Sokhna port location on Egypt map [11]

5.1 Port layout design and development of Al-Sokhna port

Al-Sokhna Port represents a major initiative launched by the Government of Egypt, situated on the Red Sea approximately 45 km south of Suez. It is an integral part of a comprehensive industrial development plan that features a 9,000-hectare Special Economic Zone dedicated to industrial facilities and enterprises. The port boasts a total quay wall length of 2,000 meters with a draft of 17 meters and is segmented into various terminals, including a container terminal, a general cargo and RO-RO terminal, a bulk terminal, and a fertilizer terminal. The initial capacity of the container terminal is approximately 400,000 TEU.

The layout design and development of Al-Sokhna Port are visually represented in Figures 4 and 5, showcasing its impressive infrastructure and operational capabilities [11]-[12]. The layout design illustrates the port's strategic planning and efficient utilization of space, with a clear emphasis on optimizing cargo handling and vessel accommodation. The development depicted in the figures highlights the port's evolution and expansion, underscoring its growing capacity to handle increased volumes of cargo and accommodate a diverse range of vessels.

Figure 4: Al-Sokhna port map [10]

Figure 5: Al-Sokhna port detailed map [12]

Moreover, Figure 5 conveys the port's modern facilities and specialized berths, including container berths, RORO berths with inbuilt ramps, general cargo berths, and multipurpose berths, each contributing to the port's versatility and ability to cater to various types of cargo and shipping needs [12]. This portrayal of the port's layout design and development emphasizes its status as a significant maritime hub with the infrastructure to support international trade and economic growth.

5.2 Competitive advantages of Al-Sokhna port

Al-Sokhna Port boasts several competitive advantages, including: 1. Strategic location (both maritime and terrestrial), 2. Serving as an optimal gateway for cargo traveling to and from the Far East, Gulf region, and East Africa, 3. Short inland distance to Egypt's largest industrial centers (6th of October and 10th of Ramadan), 4. The first and only fully automated terminal among Egyptian ports, 5. Potential for expansion and development (Basin II project and total land area), and 6. Access to over 30 customer service representatives for support and assistance [10]-[14]. The port different information and port berth’s data are clarified in Tables 1 and 2 respectively.

Table 1. Al-Sokhna port information [10]

Coordinate	
Longitude	32^{o} 21.4′ E
Latitude	27^{o} 39′ N
Natural Characteristics	
Weather	Northern to North-Western winds
Water Density	1.04 g/cm^3
Raining Season	Winter
Tidal range and flow	1.2 m. to 2.1 m.
Port Features	
Total Area	87.8 km^2
Water Area	65.5 km^2
Land Area	22.3 km^2

Table 2. Al-Sokhna Berth information according to its types [10]

Berth types	*Number of Berths*	*Length (m.)*	*Width (m.)*	*Depth (m.)*
RORO	2	200m	30m	17m
Bulk and General	1	750m	30m	17m
Container	1	750m	30m	17m
Tug Craft	1	200m	-	5.5m
Support Units	1	200m	-	5.5m
Third Dock	1	350m	-	17m
Total	7	2350m	-	

6. SYSTEM SIMULATION, RESULTS AND DISCUSSION

The research results support the strategic future plan to replace traditional transport vehicles with electric vehicles in Egypt, which includes Al-Sokhna Port. This transition to electric vehicles is expected to reduce environmental impact by securing renewable electricity and transitioning to a more sustainable business model. Furthermore, the extension of Al-Sokhna Port in Egypt used electric vehicles, which are estimated to reduce well-to-wheel greenhouse emissions.

The targeted study is applied to 85 EVs in Al-Sokhna port per typical operating day. Considering the port operation assigned schedules and restricting to all the speed, weight, trip or stroke distance, power and energy constraints, the results shown in Table 3 and Figures 6 and 7 are obtained by solving the main optimization objective function with the charging constraints. Table 3 presents the number of trucks (EV) which should be charged, the duration of charging and the starting time of charging (also shown in Figure 6). It also illustrates the charging energy needed for each duration of charging by the whole number of trucks in MWh. The reduction in CO_2 emissions in kgCO_2 is clarified in both Table 3 and Figure 7 which indicate overall reduction equals to 34200 kgCO_2/ day with equivalent cost reduction equals to 1710 $/day.

Table 3. Al-Sokhna port EVs scheduling results

Number of Trucks	*Starting Time of Charging*	*Duration of Charging (hours)*	*Starting Time of Operation*	*Charging Energy (MWh)*	*CO_2 Reduced Emissions (kgCO_2)*	*Cost Reduction ($)*
30	01:00 am	8	09:00 am	30*0.6 + 2 = 20	12000	12*50 = 600
25	09:00 am	8	05:00 pm	25*0.6 + 2 = 17	10200	10.2*50 = 510
30	05:00 pm	8	01:00 am	30*0.6 + 2 = 20	12000	12*50 = 600
Total				47 MWh/day	***34200 /day***	***1710 $/day***

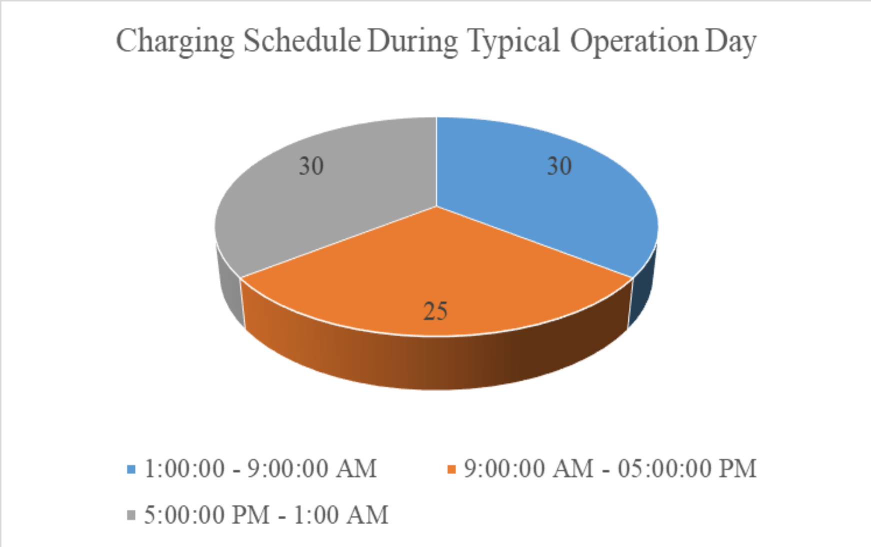

Figure 6 : EVs charging schedule in Al-Sokhna port

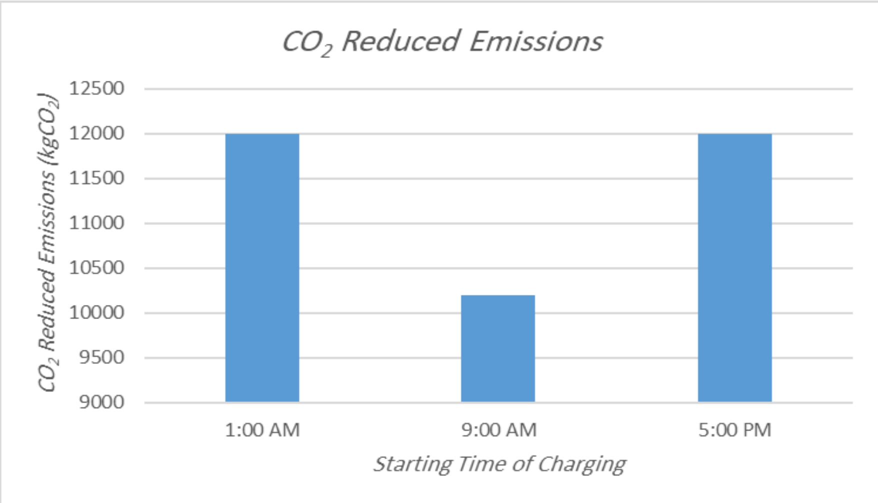

Figure 7: The reduction in CO_2 emissions per typical day due to EVs utilizing in Al-Sokhna port

7. CONCLUSIONS

This study provides a comprehensive analysis of the environmental impact of intelligent transportation scheduling for electric vehicles eco-friendly charging in Al-Sokhna port. The results have illustrated that the implementation of intelligent scheduling systems based on renewable electricity resources charging system, in conjunction with electric vehicles significantly diminishes environmental pollutants, primarily carbon dioxide emissions. The intelligent scheduling not only optimizes the use of vehicles, but it also minimizes energy consumption and decreases idle time, which further promotes energy efficiency. These findings corroborate the hypothesis that the integration of smart technologies in port operations can catalyze a reduction in environmental impact.

Intelligent Discrete Water Cycle Optimization Algorithm (DWCOA) is programmed using Matlab/m-file to determine the optimal schedule, capacity, and CO_2 emission reduction for the EVs. DWCOA is used to solve the system objective function considering the boundary values, conditions, limitations, and constraints to find the optimal EVs charging-operation schedule. The results of applying the aimed study to 85 electric trucks in Al-Sokhna port clarify that 34200 kgCO_2/ day can be reduced which represents around 88% from the emissions of fossil fuels trucks. Also, a daily $ 1710 cost saving can be fulfilled.

However, the study has also underscored potential challenges in the transition to intelligent transportation schedules for electric vehicles. These include the need for infrastructure development, technology adoption, and comprehensive operator training. It highlights the critical need for a concerted effort from all stakeholders to overcome these barriers and achieve successful implementation. The findings of this study establish a significant precedent for the environmental potential of intelligent transportation schedules for electric vehicles in port settings. They provide a pathway for other ports to follow, emphasizing the importance of such systems in achieving broader environmental sustainability targets.

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