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STUDY ON RADIO DIRECTION ESTIMATION ALGORITHMS

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Abstract : The presented paper analyses the steps by which radio direction estimation algorithms are used to visualize the direction from which a radio signal originates. This study aims to use ULA (Uniform Linear Array) and URA (Uniform Rectangular Array) antennas and integrate them into a simulation in order to find the direction of origin of the signals, what the contrast between the phase and time differences is when the signal reaches the antennas and how the systems for estimating the directions of arrival (DOA) affect the signal at the receptor . The difference between ULA and URA antennas is exemplified by using them in a more complex system that can be implemented physically and not just digitally. These two arrays of antennas have several particularities such as the DOA algorithms used by each antenna, its angled directions and their representation from a matrix point of view. The simulation was conducted as a preliminary study for a hardware implementation of this system using a USRP N 310 software defined radio platform.
Key words : radio, simulation, direction of arrival, antenna, algorithm.

1. INTRODUCTION

This paper explores several methods for estimating the direction of arrival (DoA) of a received radio signal by determining its precise azimuth and elevation angles. The study focuses on simulation techniques such as Uniform Linear Array (ULA), Uniform Rectangular Array (URA), Minimum Variance Distortion less Response (MVDR), and Multiple Signal Classification (MUSIC). In addition to simulation, the work includes a planned hardware implementation using the USRP N310 software-defined radio. It should be noted, however, that the hardware implementation has not yet been realized at the current stage of the work.

2. MATERIALS AND METHODS

2.1 MATLAB Simulation Software

The program used to analyse the behaviour of a radio wave, determining the direction of origin, as well as azimuth and elevation angles, is MATLAB. For the purpose of estimating the radio direction, two types of antennas will be used: ULA (Uniform Linear Array) and URA (Uniform Rectangular Array). They use specific methods that will allow the differences between them to be compared, the performance of each method being evaluated in terms of the accuracy of the estimation of steering angles [1].

2.2 Azimuth angle

The angle between a reference direction (usually the north) and the horizontal projection of an object is defined as an azimuth angle. It is measured clockwise from 0 degrees to 360 degrees. In this project it is used to observe the horizontal direction from which a signal comes (a group of antennas will be used as a reference point or an array of antennas). In radio direction estimation systems, this angle is used to direct the signal flow to a particular device, identify a signal source, and locate objects through reflected signals. This angle can be analysed with ULA and URA antennas.

2.3 Elevation angle

This angle represents the angle between the direction of an object and the horizontal plane. It can be measured from 0 degrees to 90 degrees. In radio direction systems, the elevation angle is used to indicate the height from which a signal originates in relation to the horizontal plane of an antenna group or antenna array (both types will be exemplified in this project). The elevation angle can be used in DOA (Direction of Arrival) systems to determine the position of an object and to optimize the signal in wireless communications. It can only be viewed in applications using URA (Uniform Rectangular Array) antennas, as this alone allows the simultaneous use of both angles: elevation and azimuth.

2.4 DOA algorithm

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DOA (Direction of Arrival) is a technique used to approximate the direction from which a certain signal originates, i.e. to determine the angle of origin of a signal in relation to an array of antennas (this term is used to describe an array of antennas that function as a set of sensors). This algorithm is based on a set of data collected from several sensors, with the aim of estimating the direction of origin of the signal, by processing the information obtained. DOA algorithms can use several techniques such as beam scan, MVDR and MUSIC, these being specially designed to be able to locate signal sources [2].

2.5 ULA (Uniform Linear Array)

The Uniform Linear Array is an array of antennas that are positioned in a straight line, having equal distances from each other. This configuration is used in radio direction estimation systems. The process of operation of this type of arrangement is very easy to understand. Each antenna in ULA receives signals from different sources causing the signals to arrive with a phase delay conditioned by the angle of arrival of each signal. By comparing these phase shifts, the angle of arrival of the signal can be estimated.

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2.6 URA (Uniform Rectangular Array)

Uniform Rectangular Array is a type of antenna array that is placed in a uniform array configuration, in two dimensions (horizontal and vertical). They are placed as ULA antennas, at the same distance from each other, horizontally and vertically. The main difference between the two types is that the ULA (Uniform Linear Array) covers a one-dimensional line, while the URA (Uniform Rectangular Array) covers a two-dimensional space. The two-dimensional configuration has a wider coverage and offers the possibility of scanning angles from two directions (azimuth and elevation). A signal that reaches an URA will reach the antennas in the array with a different phase shift, depending on the angle of arrival on both the horizontal and vertical axis. In the case of an URA, two angles will be calculated: the azimuth angle and the elevation angle. The phase shifts for each antenna in both directions (horizontal and vertical) are used to estimate these angles.

2.7 Beam scan algorithm

Beam scan is a simple method of estimating the direction of some radio signals in an antenna array system such as ULA and URA. The main idea is to "scan" different angles of arrival of the signal and calculate the signal strength at each angle. This method can be applied in both types of antenna arrays, but there are significant differences in the way the algorithm is implemented for each of them, due to the distinct configurations of the two types of arrays. In estimating angles, for ULA, Beam scan involves scanning the arrival angles of the signal in a single direction (azimuth angle), For URA, it involves scanning two arrival angles, considering both the azimuth angle (in the horizontal plane) and the elevation angle (in the vertical plane). In the case of ULA, the angular resolution of the direction estimate is restricted to a single angle. If two signal sources are almost in the same direction of arrival (but not identical), the Beam scan algorithm may not differentiate them effectively because it only analyses angles on a single (one-dimensional) axis. On the other hand, in the case of the URA array, due to its two-dimensional configuration, the Beam scan algorithm can provide a higher resolution in detecting signals, including those that are close in both the horizontal and vertical planes.

2.8 MVDR algorithm

MVDR (Minimum Variance Distortion less Response) is a beamforming technique (it can focus the signal in a specific direction, making it easier to identify the direction from which the transmitted or received signal has its maximum intensity) that captures the desired signal from a specific direction, while attenuating interference and noise from other directions.

This technique is used for both types of arrays, ULA and URA. The main differences in the use of MVDR are related to the size and complexity of the array. While ULA only allows for single-direction signal estimation, URA extends this capability to three-dimensional space, allowing scanning in both horizontal and vertical directions. This makes MVDR in URA more complex in terms of estimating the covariant matrix, which is essential for estimating the direction from which signals originate, but at the same time more efficient in complex environments where interference comes from multiple angles.

2.9 MUSIC algorithm

MUSIC (Multiple signal classification) is an algorithm that helps to identify the direction of arrival of an emitted radio signal based on spectral analysis and decomposition of the covariant matrix.

This decomposition of the matrix is performed because it is desired to extract useful information from a signal that is then used to find out the direction of arrival of the signal, but also to separate the signals from noise, performing a more accurate spectral efficiency.

This method is used in both ULA and URA systems, which of these types of antenna arrangements is more suitable for performing this technique. In a linear array (ULA), the antennas are placed only on a single axis, if the distance between the antennas is greater than $\lambda/2$, spatial aliasing may occur, which means that different directions of the signal become indistinguishable (signals coming from different angles may appear to be coming from the same direction). For a rectangular array (URA), the antennas are placed in two axes, which allows signals

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to be processed in two different directions (azimuth and elevation), helping to correctly distinguish between signal sources.

3. RESULTS AND DISSCUTIONS

Following several published papers about DOA systems, a simulation of the radio direction estimation system was made using the MATLAB software, materializing several conclusions regarding the use of reception techniques using ULA and URA antennas [4].

3.1 Beamscan, MVDR and MUSIC techniques in an ULA antenna system

In this section, several techniques are explored for estimating the direction of arrival (DOA) of radio signals using a Uniform Linear Array (ULA)**.** Accurate DOA estimation is crucial for applications in radar, wireless communication, and signal processing. Three methods: Beamscan, MVDR (Minimum Variance Distortionless Response), and MUSIC (Multiple Signal Classification) are analysed and compared to assess their effectiveness in detecting and differentiating multiple signals. The study begins with Beamscan**,** a basic method that relies on azimuth angles but struggles to separate closely spaced signals. To improve accuracy, MVDR is introduced, offering better resolution but still facing challenges in distinguishing signals that are too close. Finally, the MUSIC algorithm is tested, demonstrating superior performance by effectively resolving signals even in noisy environments. Through this comparison, we aim to highlight the strengths and limitations of each technique and determine the most reliable approach for precise DOA estimation.

3.1.1 Beamscan-ULA

A simulation was made to estimate the radio direction using two signals in order to observe the difference between the effectiveness of the techniques. The first method, since it is made for a ULA antenna array, only the azimuth angle of the signal can be used.

In MATLAB, a code was created in which the following characteristics were applied: the number of elements in the ULA array, 4 antennas with a spacing of 0.5 meters between them; the angle of the first signal is 40 degrees and the second signal has an angle of -20 degrees (these angles can vary between -90 degrees and +90 degrees); the speed of light together with a frequency of 300 MHz, both in order to be able to perform the wavelength calculation. A 4-antenna ULA was chosen because it can be implemented with the USRP N310, which has only four input channels.

However, as shown in the following figures, using a ULA with 16 antennas leads to significant improvements in the results. In Figure 2, the graph is much more precise, clearly distinguishing between the two signals. In contrast, Figure 1 shows the signals are distinguishable, but with a limited antenna array, the distinction is less clear. Although it's possible to link multiple antennas in the array, a larger antenna configuration is more efficient. The constraint of using the USRP N310 limits the system to only four connected antennas, which affects the antenna array design.

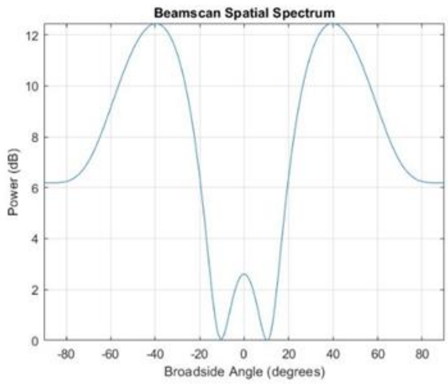

Figure 1 Beamscan Spatial Spectrum with azimuth angles of -40 and 40 degrees using an ULA with 4 elements

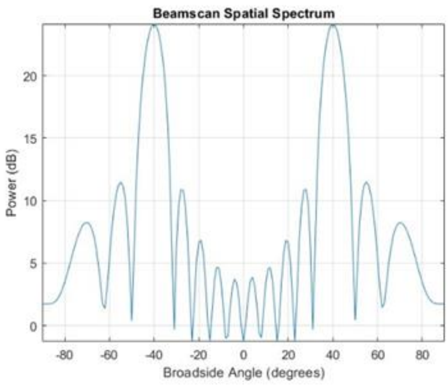

Figure 2 Beamscan Spatial Spectrum with azimuth angles of -40 and 40 degrees using an ULA with 16 elements.

To test the performance of the Beamscan algorithm under conditions where the signals are closer angularly, two experiments were performed. In Figure 3, two signals with angles of -10° and 15° were considered, using a 4-element array.

In Figure 4, the same angles were maintained, but with an array of 16 antennas, to observe how the number of elements influences the resolution and performance of the algorithm in detecting nearby signals.

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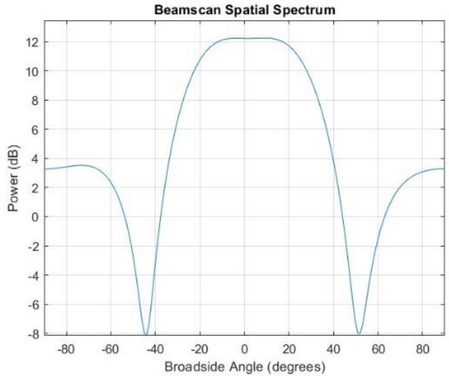

Figure 3 Beamscan Spatial Spectrum with azimuth angles of -10 and 15 degrees using an ULA with 4 elements.

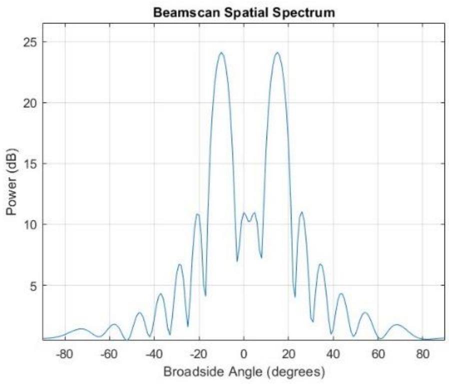

Figure 4 Beamscan Spatial Spectrum with azimuth angles of -10 and 15 degrees using an ULA with 16 elements.

It can be seen that in Figure 3 the two received signals are no longer distinct, which makes the array of 4 antennas not sufficient for the Beamscan algorithm, because it can no longer differentiate the signals located at a small angular distance.

In contrast, in Figure 4, the use of a 16-antenna array allows the Beamscan algorithm to clearly distinguish the two signals, even at an angular difference of only 25 degrees, thus demonstrating its improved ability to resolve close signals when using a larger number of antennas.

Figure 5 illustrates that the Beamscan algorithm detects a single, fainter lobe, instead of the two distinct signals that should be present.

The signals are separated by a 10° angle, and the array configuration includes only 4 elements, which limits the angular resolution capability.

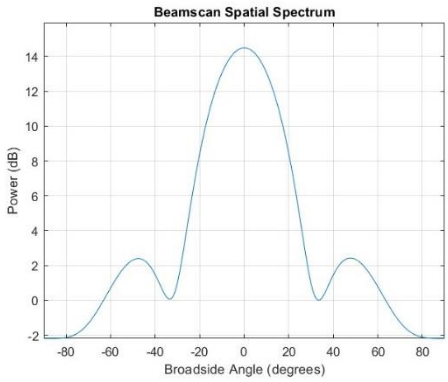

Figure 5 Beamscan Spatial Spectrum with azimuth angles of -5 and 5 degrees using an ULA with 4 elements.

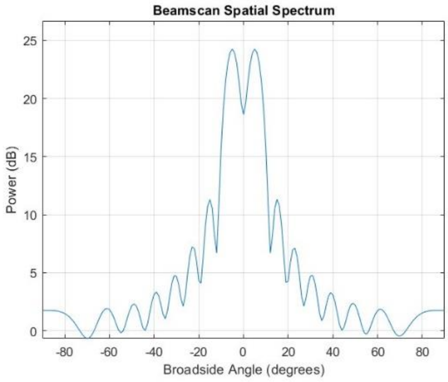

Figure 6 Beamscan Spatial Spectrum with azimuth angles of -5 and 5 degrees using an ULA with 16 elements.

In contrast, Figure 6 clearly highlights the two distinct signals, thanks to the use of an array consisting of 16 antennas. These results show that the performance of the Beamscan algorithm is closely related to the number of elements in the array – a reduced number of antennas does not allow an efficient separation of nearby signals, while a higher number of elements significantly improves the differentiation capacity.

3.1.2 MVDR-ULA

The difference between Figure 7 and Figure 8 lies in the width of the lobes of the detected signals.

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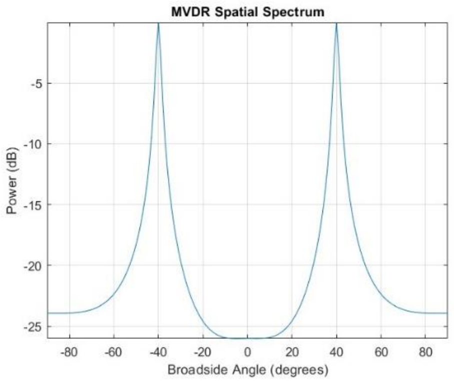

Figure 7 MVDR Spatial Spectrum with azimuth angles of -40 and 40 degrees using an ULA with 4 elements.

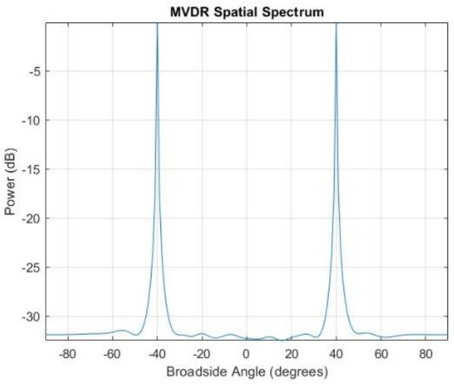

Figure 8 MVDR Spatial Spectrum with azimuth angles of -40 and 40 degrees using an ULA with 16 elements.

In Figure 7, where only 4 antennas were used, the signals appear wider and less angularly precise.

On the other hand, in Figure 8, the use of an array consisting of 16 elements allows to obtain much narrower lobes, which contributes to a more precise location of the direction of origin of the signals.

This comparison highlights that as the number of elements in the array increases, the angular accuracy of the MVDR algorithm improves significantly, allowing for a clearer and more accurate estimate of the signal direction.

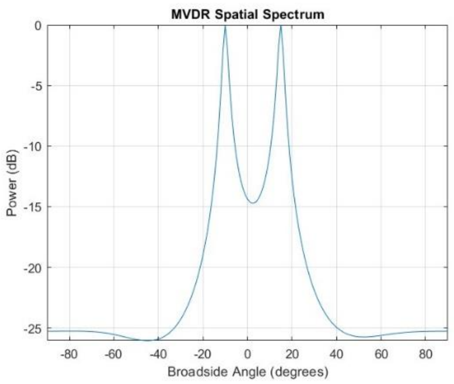

Figure 9 MVDR Spatial Spectrum with azimuth angles of -10 and 15 degrees using an ULA with 4 elements.

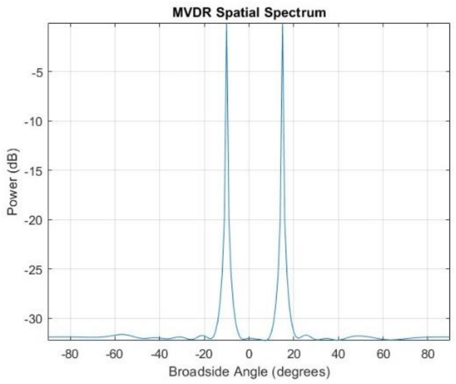

Figure 10 MVDR Spatial Spectrum with azimuth angles of -10 and 15 degrees using an ULA with 16 elements.

Figure 9 presents the tendency of the two signals to partially overlap as a result of the angular proximity between them, which affects the separation capacity when using a small number of elements in the array. In contrast, Figure 10 highlights a clear delimitation of the two signals, thanks to the use of a 16-antenna array.

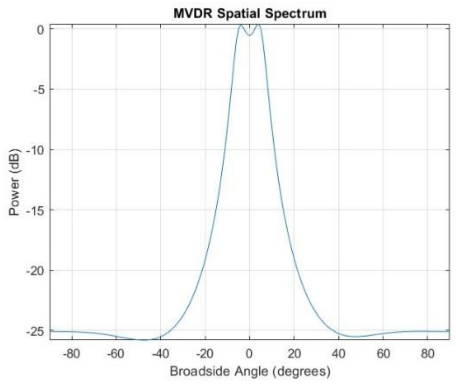

Figure 11 MVDR Spatial Spectrum with azimuth angles of -5 and 5 degrees using an ULA with 4 elements.

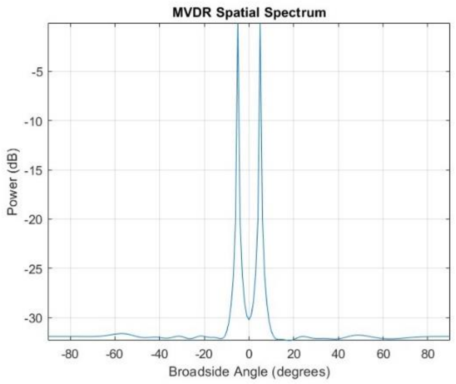

Figure 12. MVDR Spatial Spectrum with azimuth angles of -5 and 5 degrees using an ULA with 16 elements.

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Figure 11 illustrates the results obtained with the MVDR algorithm for the reception of two signals at an angular distance of 10° in the azimuth plane. Even when using an array with a small number of elements, the algorithm manages to highlight, albeit partially, the presence of both signals. In Figure 12, where 16 elements were used in the array, the separation of the two signals becomes much clearer, demonstrating the MVDR algorithm's superior ability to resolve angle-close signals. Compared to Beamscan, MVDR offers better angular resolution, making it more effective in scenarios where signal sources are directionally close.

3.1.2 MVDR-ULA

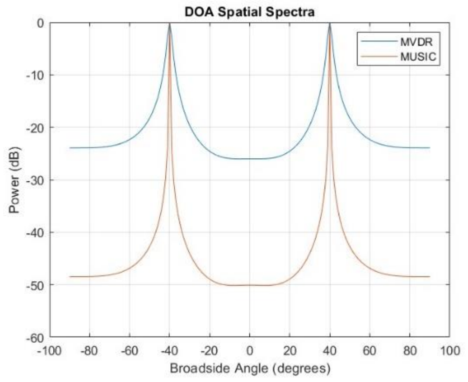

Figure 13 MUSIC Spatial Spectrum with azimuth angles of -40 and 40 degrees using an ULA with 4 elements.

Figure 13 demonstrates a comparison between the MVDR and MUSIC algorithms, in the context of two signals separated by an 80° angle.

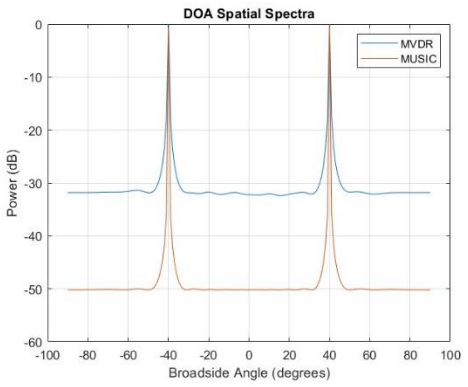

Figure 14. MUSIC Spatial Spectrum with azimuth angles of -40 and 40 degrees using an ULA with 16 elements.

One can observe the behaviour of each algorithm in estimating the direction of arrival (DOA) for a wide angle of separation. Figure 14 illustrates the comparison between the two algorithms again, but this time the superiority of the MUSIC algorithm in terms of signal clarity and uniformity is highlighted. MUSIC provides a more accurate and well-defined representation of signals, compared to MVDR, which underlines its increased efficiency in such scenarios.

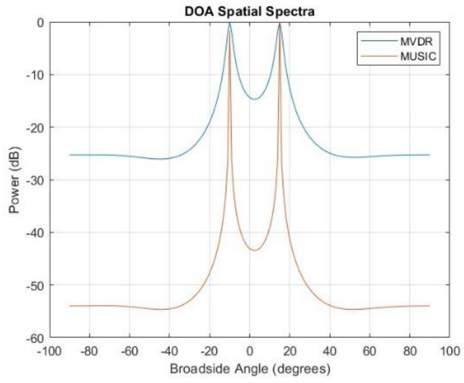

Figure 15. MUSIC Spatial Spectrum with azimuth angles of -10 and 15 degrees using an ULA with 4 elements.

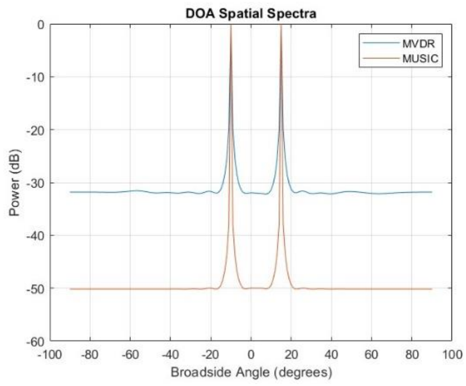

Figure 16. MUSIC Spatial Spectrum with azimuth angles of -10 and 15 degrees using an ULA with 16 elements.

Figure 15 illustrates the same comparison between the MVDR and MUSIC algorithms, but for a small angular distance between the signals, of 25°. Figure 16, where an array of 16 elements was used, shows that the MUSIC algorithm continues to deliver high performance. Comparing the two situations, it can be concluded that MUSIC is able to operate efficiently even with a small number of elements (4 antennas), providing results comparable to those obtained in configurations with a larger number of antennas. However, the increase in the number of elements contributes to improved accuracy and signal separation capacity, highlighting the additional benefits of using a denser array.

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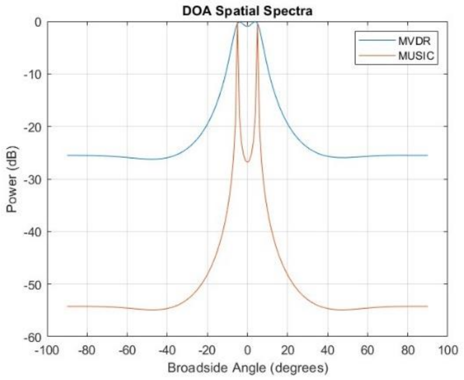

Figure 17 MUSIC Spatial Spectrum with azimuth angles of -5 and 5 degrees using an ULA with 4 elements.

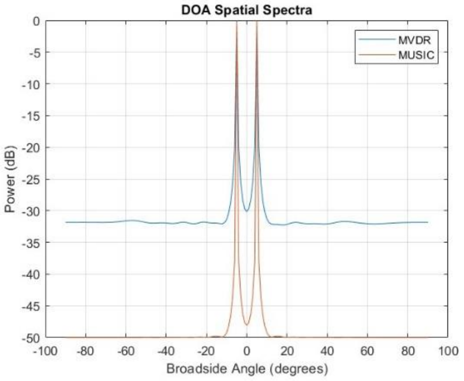

Figure 18 MUSIC Spatial Spectrum with azimuth angles of -5 and 5 degrees using an ULA with 16 elements.

Figure 17 highlights the performance differences between the MVDR and MUSIC algorithms when using a 4-element array. The results show that the MUSIC algorithm provides a higher spectral resolution, managing to more efficiently separate the two received signals, which become clearly visible, unlike MVDR. In Figure 18, the same comparison is made using an array of 16 elements. In this case, both algorithms – both MVDR and MUSIC – offer comparable performance, managing to clearly distinguish the two signals, which demonstrates that, with the increase in the number of antennas, the differences between the two methods diminish.

3.2 Beamscan, MVDR and MUSIC techniques in a URA antenna system

In this section, the performance of different Direction of Arrival (DOA) estimation techniques is analyzed for a Uniform Rectangular Array (URA). Unlike the Uniform Linear Array (ULA), which only considers the azimuth angle, a URA system allows for the estimation of both azimuth and elevation angles, making it more suitable for three-dimensional signal detection. The Beamscan method is first applied to a 2X2 URA and second to a 16x16 URA with specific element spacing, using a 2D Beamscan technique to estimate signal directions. While Beamscan provides a basic visualization of DOA, it has limitations in resolution. Next, the MVDR (Minimum Variance Distortionless Response) method is explored, offering higher accuracy but suffering from excessive sensitivity, which can sometimes lead to errors in signal direction estimation. Finally, the MUSIC (Multiple Signal Classification) algorithm is evaluated, demonstrating superior accuracy in estimating both azimuth and elevation angles, albeit with increased computational complexity. By comparing these three techniques, the aim is to determine the most effective method for accurately estimating DOA in URA systems while considering their respective strengths and weaknesses.

3.2.1Beamscan-URA

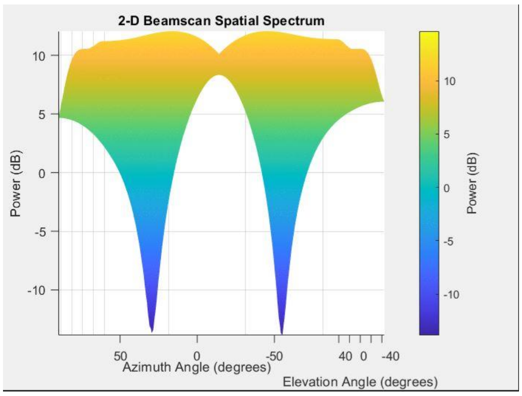

Figure 19. 3D spectrum for a 2-D Beamscan. For the first signal was used the elevation angle of 30 degrees and for azimuth angle -40 degrees. For second signal used the elevation angle -25 degrees and for azimuth angle 40 degrees using an URA with 4 elements.

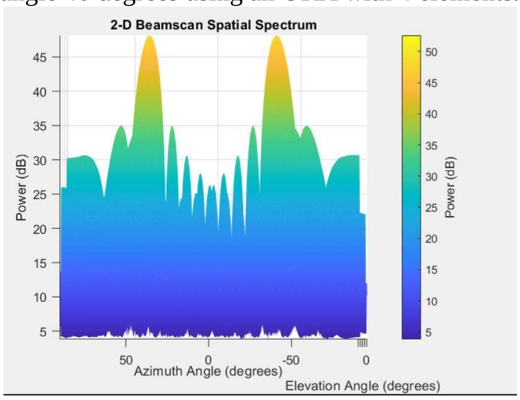

Figure 20 3D spectrum for a 2-D Beamscan. For the first signal was used the elevation angle of 30 degrees and for azimuth angle -40 degrees. For second signal used the elevation angle -25 degrees and for azimuth angle 40 degrees using an URA with 16x16 elements.

Figure 19 illustrates the three-dimensional spectrum generated by the Beamscan algorithm using a uniform

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rectangular array (URA) of type 2×2. This configuration allows the simultaneous representation of the directions of arrival in the azimuth and elevation planes. However, due to the small number of elements, the spatial resolution is limited. Figure 20 shows a significantly improved version of the same algorithm, where a 16×16-element URA array was used. The results show a clear and precise separation of the two signal sources, highlighting the advantage of using a dense array of antennas to achieve higher resolution in both planes.

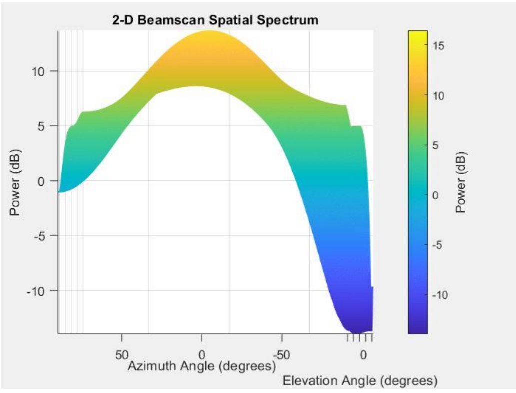

Figure 21 3D spectrum for a 2-D Beamscan. For the first signal was used the elevation angle of 20 degrees and for azimuth angle -10 degrees. For second signal used the elevation angle -10 degrees and for azimuth angle 15

Figure 21 presents the limitations of the Beamscan algorithm when the two signals are angled together, using a 2×2 size URA antenna array. In this configuration, the algorithm is no longer able to properly distinguish the two sources, due to the low spatial resolution. In contrast, Figure 22 highlights a clear separation of the same close signals, thanks to the use of an array of antennas 16×16.

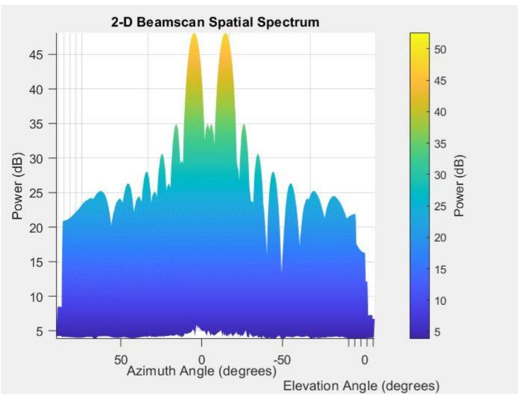

Figure 22 3D spectrum for a 2-D Beamscan. For the first signal was used the elevation angle of 20 degrees and for azimuth angle -10 degrees. For second signal used the elevation angle -10 degrees and for azimuth angle 15 degrees using an URA with 16x16 elements.

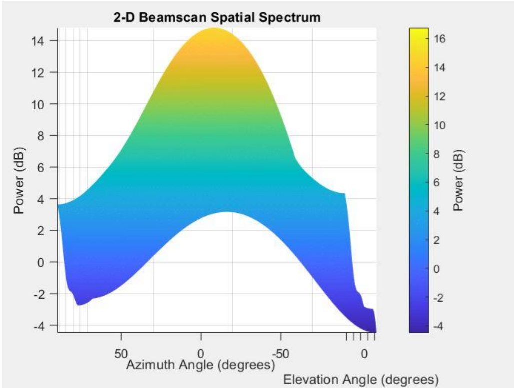

Figure 23 3D spectrum for a 2-D Beamscan. For the first signal was used the elevation angle of 10 degrees and for azimuth angle -5 degrees. For second signal used the elevation angle 5 degrees and for azimuth angle 5 degrees using an URA with 4 elements.

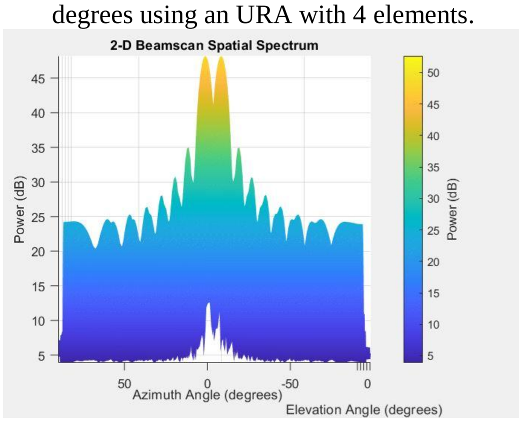

Figure 24. 3D spectrum for a 2-D Beamscan. For the first signal was used the elevation angle of 10 degrees and for azimuth angle -5 degrees. For second signal used the elevation angle 5 degrees and for azimuth angle 5 degrees using an URA with 16x16 elements.

Figure 23 shows the case of the closest signals analysed in the project, where the Beamscan algorithm is no longer able to distinguish them as separate sources, but interprets them as a single signal, due to the limited spatial resolution associated with a small matrix. In contrast, Figure 24 demonstrates that, even under conditions of accentuated angular proximity in azimuth and elevation, the Beamscan algorithm can efficiently separate the signals, provided that an array with a large number of antennas is used.

3.2.2 MVDR-URA

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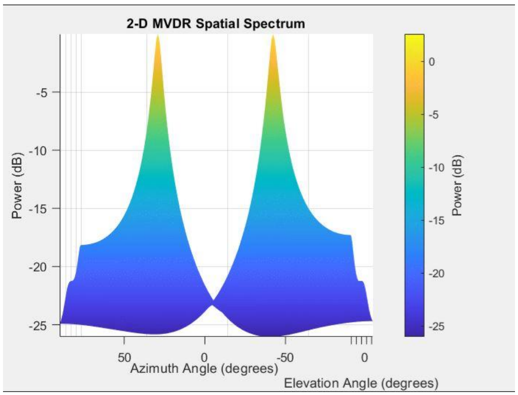

Figure 25 3D spectrum for a 2-D MVDR. For the first signal was used the elevation angle of 30 degrees and for azimuth angle -40 degrees. For second signal used the elevation angle -25 degrees and for azimuth angle 40 degrees using an URA with 4 elements.

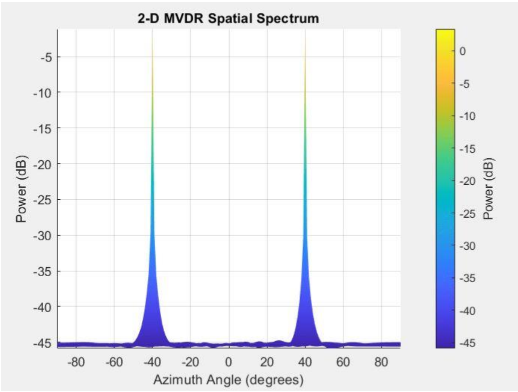

Figure 26 3D spectrum for a 2-D MVDR. For the first signal was used the elevation angle of 30 degrees and for azimuth angle -40 degrees. For second signal used the elevation angle -25 degrees and for azimuth angle 40 degrees using an URA with 16x16 elements.

Figure 25 highlights the ability of the MVDR algorithm to detect two signals located at a greater angular distance, using an array of 4 antennas. Although the separation is visible, the resolution remains limited. In Figure 26, the same situation is analysed with the help of an extended array of 16×16 elements, in which case the signals are much better defined and clearly separated.

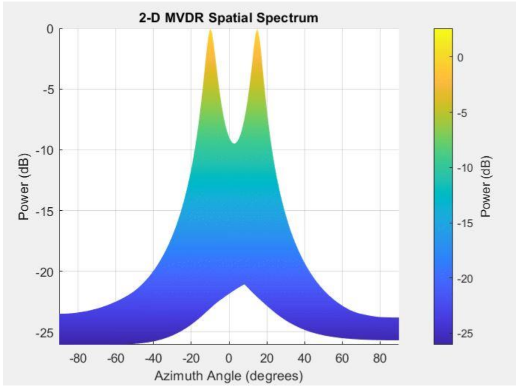

Figure 27 3D spectrum for a 2-D MVDR. For the first signal was used the elevation angle of 20 degrees and for azimuth angle -10 degrees. For second signal used the elevation angle -10 degrees and for azimuth angle 15 degrees using an URA with 4 elements.

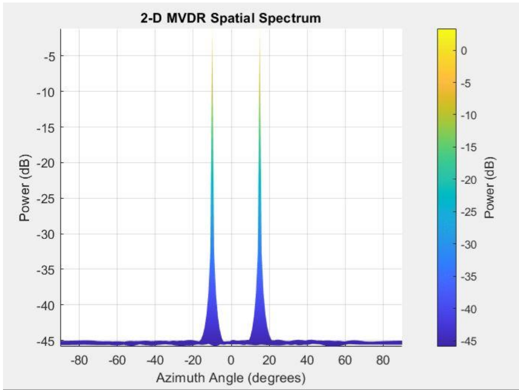

Figure 28 3D spectrum for a 2-D MVDR. For the first signal was used the elevation angle of 20 degrees and for azimuth angle -10 degrees. For second signal used the elevation angle -10 degrees and for azimuth angle 15 degrees using an URA with 16x16 elements.

Figure 27 illustrates two signals that, although close angularly, are still detected as distinct sources by the MVDR algorithm, using a small array. However, the analysis in Figure 28 shows a much clearer separation of signals when using a large array. This confirms that the performance of the MVDR algorithm is significantly improved with the increase in the number of elements in the antenna array, which allows for more accurate estimation and higher spatial resolution.

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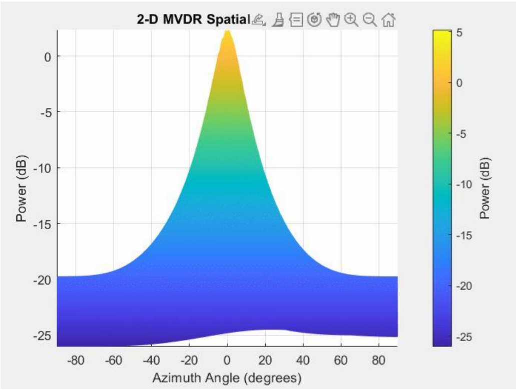

Figure 29 3D spectrum for a 2-D MVDR. For the first signal was used the elevation angle of 10 degrees and for azimuth angle -5 degrees. For second signal used the elevation angle 5 degrees and for azimuth angle 5 degrees using an URA with 4 elements.

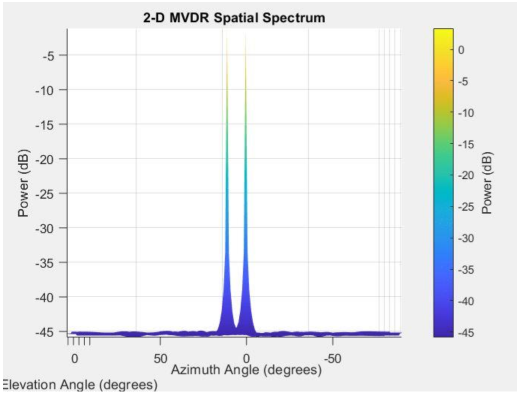

Figure 30 3D spectrum for a 2-D MVDR. For the first signal was used the elevation angle of 10 degrees and for azimuth angle -5 degrees. For second signal used the elevation angle 5 degrees and for azimuth angle 5 degrees using an URA with 16x16 elements.

Figure 29 highlights the limitations of the MVDR algorithm in the case of estimating two signals very close angularly, when using a URA (Uniform Rectangular Array) configuration with only 4 elements. In this situation, the algorithm is no longer able to correctly distinguish the two sources, due to the low spatial resolution. In contrast, Figure 30 demonstrates that by using a larger URA configuration, MVDR is able to efficiently identify and separate even the closest signals.

3.2.3 MUSIC-URA

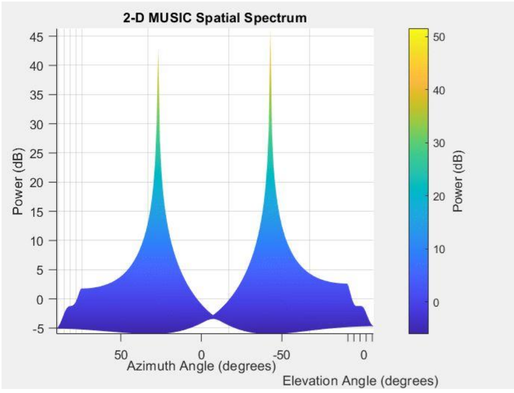

Figure 31 3D spectrum for a 2-D MUSIC. For the first signal was used the elevation angle of 30 degrees and for azimuth angle -40 degrees. For second signal used the elevation angle -25 degrees and for azimuth angle 40 degrees using an URA with 4 elements.

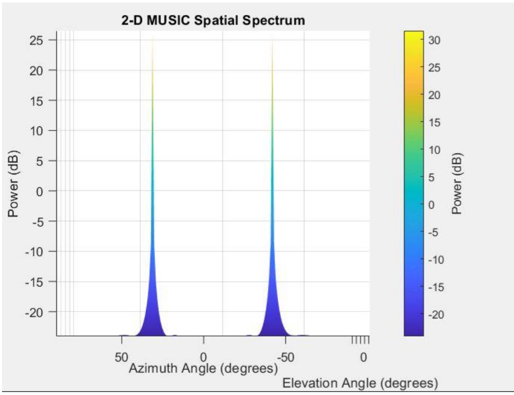

Figure 32 3D spectrum for a 2-D MUSIC. For the first signal was used the elevation angle of 30 degrees and for azimuth angle -40 degrees. For second signal used the elevation angle -25 degrees and for azimuth angle 40 degrees using an URA with 16x16 elements.

Figure 31 demonstrates the performance of the MUSIC algorithm compared to MVDR, using a 4-antenna URA configuration. It is noted that MUSIC provides superior spectral separation and more accurate signal localization, even under conditions with a low number of elements. In Figure 32, where an extended array of 16×16 elements was used, the MUSIC algorithm shows a significantly improved performance, with a much more clearly defined spectrum and a precise distinction between signal sources.

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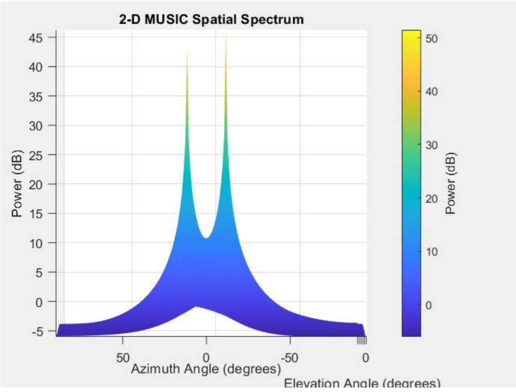

Figure 33 3D spectrum for a 2-D MUSIC. For the first signal was used the elevation angle of 20 degrees and for azimuth angle -10 degrees. For second signal used the elevation angle -10 degrees and for azimuth angle 15 degrees using an URA with 4 elements.

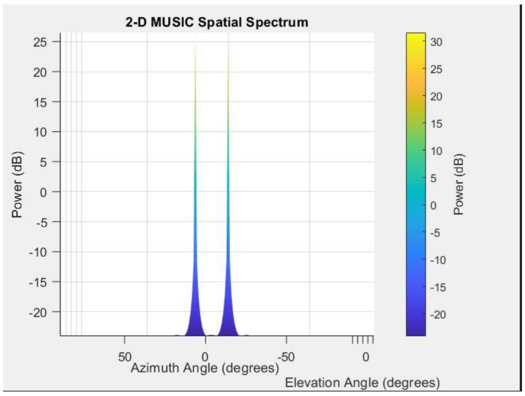

Figure 34 3D spectrum for a 2-D MUSIC. For the first signal was used the elevation angle of 20 degrees and for azimuth angle -10 degrees. For second signal used the elevation angle -10 degrees and for azimuth angle 15 degrees using an URA with 16x16 elements.

Figure 33 illustrates the result of the MUSIC algorithm in the case of two angularly close signals, showing a superior separation capacity compared to the Beamscan and MVDR algorithms in similar configurations. Although the number of elements in the array is small, MUSIC still manages to partially distinguish the two sources. In Figure 34, the use of an extended array leads to significantly improved performance, with a clear and well-defined separation in the spectrum.

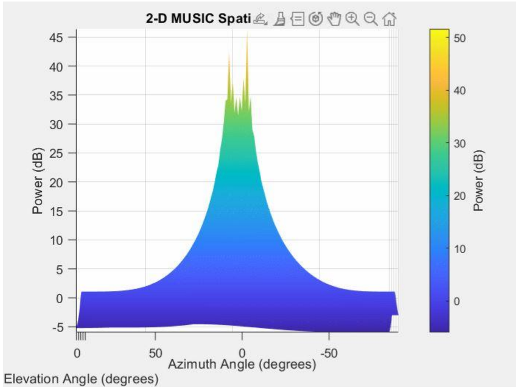

Figure 35 3D spectrum for a 2-D MUSIC. For the first signal was used the elevation angle of 10 degrees and for azimuth angle -5 degrees. For second signal used the elevation angle 5 degrees and for azimuth angle 5 degrees using an URA with 4 elements.

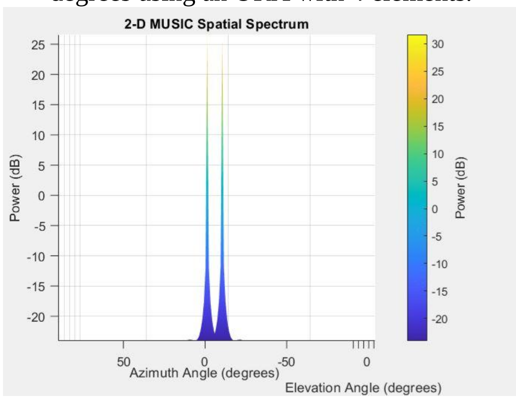

Figure 36 3D spectrum for a 2-D MUSIC. For the first signal was used the elevation angle of 10 degrees and for azimuth angle -5 degrees. For second signal used the elevation angle 5 degrees and for azimuth angle 5 degrees using an URA with 16x16 elements.

Figure 35 highlights the ability of the MUSIC algorithm to detect the presence of two signals very close angularly, even under the conditions of using an URA matrix with only 4 elements. Although the resolution is limited, the algorithm manages to suggest the existence of two distinct sources. In Figure 36, where a considerably larger array size was used, the two signals are clearly separated and well defined in the spectrum, demonstrating the superior efficiency of the MUSIC algorithm when supported by an extended antenna array configuration.

4. CONCLUSIONS

Following the analysis of the methods for estimating the direction of radio signals using the Beamscan, MVDR and MUSIC algorithms on ULA (Uniform Linear Array) and URA (Uniform Rectangular Array) antenna arrays, significant differences were highlighted

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in terms of precision, complexity and sensitivity of each technique. The results obtained demonstrated that Beamscan is a simple method, but with low resolution, being limited in the separation of nearby signals; MVDR offers higher accuracy, but is sensitive to noise and interference, which can affect the accuracy of the estimates, and MUSIC has proven the highest accuracy in estimating azimuth and elevation angles, managing to identify close signals accurately, but it is the most complex method in terms of calculations. Thus, MUSIC proves to be the best performing method, but its implementation requires greater algorithmic resources and precise mathematical modelling. The choice of the optimal method depends on the application context and the requirements of the system in terms of processing accuracy and efficiency [6].

6. ACKNOWLEDGMENTS

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INNOVATIVE LEADERSHIP IN ALIGNING SEAFARERS' SKILLS AND POLICY IN THIS ERA OF EMERGING TECHNOLOGIES: IMPLICATIONS FOR A REGIONAL STRATEGIC POLICY AND TRAINING FRAMEWORK TOWARDS SUCCESS IN A DYNAMIC WORLD

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Abstract : This paper investigates the impact of emerging technologies on seafarers' roles, focusing on how various Asia-Pacific countries are adapting their policies and skills development in the digital era. Using a descriptive research methodology—comprising observation, literature review, and content analysis, the paper explores the challenges and opportunities associated with the adoption of advanced maritime technologies and also examines the evolving landscape of seafarers' skills and policies amidst emerging technological advancements in the maritime sector, with focus on their implications for regional strategic policy development and training frameworks within the Asia-Pacific region. As digitalization, automation, and innovative maritime technologies reshape maritime operations, the demand for a highly skilled, adaptable, and technologically proficient seafarer workforce becomes paramount. The study explores current skills gaps, policy challenges, and opportunities for harmonizing regional standards to support sustainable maritime growth. Furthermore, it proposes a comprehensive strategic policy framework and a modular training program tailored to the unique needs of Asia-Pacific maritime nations, fostering resilience, safety, and competitiveness in the face of rapid technological change. Moreover, the findings also inform policymakers, industry stakeholders, and maritime education providers on effective strategies to equip seafarers with future-ready skills, ensuring the region's maritime sector remains robust and responsive to ongoing technological transformations. Ultimately, the study provide a roadmap for regional stakeholders especially in the Asian countries to harness emerging technologies effectively, ensuring a resilient, competent, and future-ready maritime workforce in the Asia-Pacific maritime context towards success in a dynamic world.

Key words **:** Blockchain, challenge, digitalization, the emerging technologies, IoT, opportunity, seafarers' skills, strategic frameworks, sustainable maritime practices.

1. INTRODUCTION

The maritime industry is currently in the **midst of a technological revolution**, propelled by rapid advancements in automation, digitalization, artificial intelligence (AI), blockchain, and the Internet of Things (IoT).

These **emerging technologies** created **impact on seafarers' roles.** As automation and autonomous ships becomes more prevalent, seafarers are increasingly required to manage complex systems, troubleshoot issues, and make strategic decisions. While these tasks may not be as physically demanding as traditional seafaring roles, they require a high level of technical proficiency and adaptability.[1] Likewise, the advent of digitalization in the maritime industry has brought about a significant shift in the way data is managed, communication is conducted, and maintenance is predicted. To navigate these changes effectively, seafarers must possess a high level of digital literacy. Similarly, the use of AI and Data analytics for route optimization, safety monitoring, and cargo management, certainly requires an understanding of data-driven decision-making.[2], [3], [4] The use of Blockchain is for_ secure transactions and documentation, that it necessitates for the seafarers to be familiar with digital credentials and cyber security awareness. Regarding IoT or Internet of Things , although sensors and connected devices enhance monitoring and maintenance, however, these requires technical adaptability on the part of the seafarers.[5]

2. METHODOLOGIES

Using a descriptive research methodology—comprising observation, literature review, and content analysis, the paper explores the challenges and opportunities associated with the adoption of advanced maritime technologies and also examines the evolving landscape of seafarers' skills and policies amidst

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emerging technological advancements in the maritime sector, with focus on their implications for regional strategic policy development and training frameworks within the Asia-Pacific region.[6], [7]

3. RESULTS AND DISSCUTIONS

3.1 Skills and Policy Alignment by Diverse Nations

To ensure that the seafarers shall continue to thrive professionally, enabling their career growth and resilience., the evolving changes underscore the critical need by countries **to strategically align seafarers' skills and policies** with these emerging technologies, **Table 1** summarizes the various country specific focuses, policies and skills in this digital era.[8], [9]

Table 1. Country-Specific Focus, Policy and Skills

Country (15)	Focus	Policy	Skills
Australia	Sustainable maritime practices and technological resilience.	Promote advanced cybersecurity, digital port operations	Cybersecurity data analytics, automation management.
Canada	Safety, environmental sustainability, and digital innovation	Update certification standards, support adaptive training programs.	Data management, environmental monitoring, and remote vessel operations.
China	Large fleet, advanced shipbuilding, and port infrastructure.	Align national standards with IMO, promote advanced certifications in automation and cybersecurity.	Automation, data analytics, cyber threat management, and port digitalization.
Chinese Taipei	Innovation in maritime technology and research	: Support lifelong learning pathways, foster industry-academia collaboration	Digital navigation, IoT systems, and maritime R&D.
India	Large seafarer workforce, digital transformatio n	Standardize digital skills certifications, promote e-learning	Cybersecurity, digital navigation, automation.
Indonesia	Developing a large seafarer workforce, port modernization	Improve digital literacy, certification recognition	Digital navigation, safety, automation basics.
Japan	Robotics, AI, and autonomous ships	Support R&D, develop specialized training pathways.	AI, automation, systems engineering
Korea	High-tech shipbuilding, autonomous vessels.	Lead innovation, develop specialized certifications.	Robotics, AI, systems integration.
Malaysia	Developing a skilled seafarer workforce for global shipping hubs.	Standardize digital certification, promote continuous professional development	Digital literacy, automation, cybersecurity.
Papua New Guinea	Focus on Capacity building for local seafarers and integration into regional maritime frameworks.	Develop national digital competency standards and strengthen regional cooperation via the Pacific Islands Forum.	Basic digital literacy, safety management, and certification recognition.
Philippines	Largest global seafarer source, need for upskilling.	Expand digital training access, recognize digital certifications	Digital literacy, cyber awareness, e-navigation.

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Singapore	Maritime digital hub, smart ports.	Harmonize regional standards, promote advanced certifications.	IoT, AI, port automation, cyber resilience.
Thailand	Regional shipping hub, port logistics.	Promote digital port management, upskill workforce.	IoT, digital documentation, automation.
USA	Cybersecurity, environmental standards.	Update certification standards, foster innovation.	Data analytics, cyber threat management, sustainable operations.
Vietnam	Growing maritime sector, workforce development.	Align training with international standards, promote regional cooperation.	Automation, cybersecurity, digital documentation.

The **policy and skills alignment** is not just a matter of adapting to change, but a crucial step towards ensuring the safety, efficiency, and sustainability of the maritime industry.

3.2 Key Challenges and Opportunities

The **Asia-Pacific region** is a global maritime hub, hosting major shipping nations, shipbuilding industries, and a large seafarer workforce. These rapid adoption of emerging technologies presents both **challenges and opportunities.**

Challenges include Resistance to change among traditional seafarers and experienced seafarers; Skill gaps in digital and technological competencies; Inadequate or outdated training frameworks; Limited awareness of career pathways in emerging tech sectors; Variability in policies across nations and companies; High costs associated with training and technology adoption; Cyber security vulnerabilities and risks**; and** Ensuring inclusivity and equal access to training globally across diverse communities On the other hand**, Opportunities** include Enhanced safety, operational efficiency, and environmental performance; New career pathways in maritime digitalization, cybersecurity, automation, and maritime technology sectors; Improved environmental sustainability through optimized operations**;** Strengthening resilience and adaptability of the maritime workforce**;** Creating new employment avenues, improving employability, and enhancing career progression prospects; and Leadership roles in maritime innovation and technology management.

3.3 Proposed Regional Policy and Training Framework

For **diverse nations** like those 15 countries listed on **Table 1**, **aligning skills and policies** is vital to ensure seafarers' career growth, safety, and industry competitiveness amid these technological shifts. Considering the specific context, strengths, and challenges of countries in embracing Emerging Technologies, a regional policy and training framework for the Asia-Pacific maritime sector is proposed to align seafarers' skills with emerging technologies in the maritime industry based on the principles for Regional and National Alignment. The **Five Principles for National and Regional Alignment** are Harmonization of standards to facilitate mobility and mutual recognition; Continuous skills development aligned with evolving industry needs; Inclusion of emerging technologies in education and certification frameworks; Promotion of industry-government collaboration for innovation and workforce resilience and Focus on sustainability, safety, cyber security, and soft skills alongside technical skills.[10], [11]

The Vision is to develop a **resilient, digitally literate global seafarer workforce**, capable of operating and managing advanced maritime technologies safely and efficiently. The **Objectives** are to integrate emerging technologies into maritime operations; Equip seafarers with relevant technical and soft skills; Foster continuous professional development; establish international and national standards for digital competencies and promote cybersecurity and safety awareness. **Table 2** presents the proposed national and regional strategic pillars with its objectives and strategic actions for skills and policy alignment.[12]

Table 2. Proposed Regional Strategic Pillars (National and Regional)

Regional Strategic Pillars	Objectives	Strategic frameworks and Actions for Skill and Policy Alignment
1. Regulatory, Standards Development, and **Harmonized Policy Development**	Develop a regional framework aligned with IMO standards, tailored to the Asia-Pacific context	Policy and Regulatory Alignment **a. Update International Standards** (International Maritime Organization) frameworks like the STCW

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		Convention must evolve to include digital competencies. - Revise IMO's STCW Convention to embed digital and technological competencies. - IMO - Establish certification pathways for emerging skills - Establish a regional maritime digital competency standard through ASEAN, APEC, or BIMSTEC collaboration. - Develop Certification Standards - Establish globally recognized certifications in digital competencies -.Promote mutual recognition of digital certifications and qualifications) - Establish mentorship and career development schemes. - Facilitate regional and global networking platforms. b. **National Policy Initiatives** (Countries should develop national strategies for

		digital skills, certifications, and continuous professional development.) - Establish national policies for digital skills accreditation Develop national frameworks for continuous professional development (CPD). - - Incentivize maritime companies to invest in training and career development. - Recognize and credential digital skills formally. -Ensure inclusive policies by addressing digital divides to include seafarers from developing regions. **c. Port and Industry Engagement and Collaboration** (Harmonized policies across ports, shipping companies, and regulatory bodies to facilitate seamless technology adoption.) - Promote industry-led training programs. **d. Safety and Security**

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		Regulations - Updated protocols to address cybersecurity risks and automation safety standards. - .Coordinate cyber security policies to protect maritime infrastructure
2. Strengthen **Maritime Education and Skill Development**	Upgrade maritime education institutions to include emerging tech.	1.Curriculum Development -Integrate Technology Training into Maritime Education -Update or revise maritime curricula by integrating digital skills (digital literacy, automation, cyber safety, and data analytics) - Facilitate exchange programs among regional maritime academies. -Promote industry-academia partnerships for practical training, and - Develop specialized certification programs in maritime technology 2.Training Needs, Competency, and Skill Development for Career

		Progression a**. Core Digital Skills** - Operating automated and integrated systems. - Cybersecurity awareness and best practices. (Protecting vessels and data from cyber threats.) - Data analytics and decision support tools. - Digital documentation and blockchain literacy. **b. Specialized Technical Skills** - Maintenance, Operating, and troubleshooting of automation and Digital systems. - Software programming and system integration. - Cybersecurity incident management. c**. Soft Skills** - Adaptability and lifelong learning mindset. - Leadership in technological change. - Problem-solving and critical thinking. In dynam2.2ic environments. - Cross-cultural communication in digital environments. d. **Career Pathways** - Technical specialist roles

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		(e.g., automation, cybersecurity). - Digital officers or cyber safety managers. - Maritime data analysts or IT coordinators. - Leadership roles in innovation and digital transformation <u>3. Career Development Programs</u> a. **Continuous Learning & Upskilling** - E-learning platforms, webinars, and virtual classrooms. - Short-term certification courses in digital and tech skills. - Industry internships and secondments in tech-focused roles. b. **Talent Identification & Succession Planning** - Use digital tools to identify high-potential seafarers. - Create clear career ladders with progression milestones. - Support leadership development in tech-driven roles. c. **Supportive Policies** - Flexible training options for working seafarers. - Recognition of prior learning and experience. - Career counselling and guidance services.
3.**Industry and Government Collaboration**	Foster public-private partnerships to pilot innovative solutions—	1. Support regional innovation hubs for maritime technology 2. Encourage shipping companies to adopt digital tools and share best practices 3. Develop regional pilot projects for autonomous ships and smart ports. 4 Collaborate with tech companies for training and innovation. and 5. Facilitate knowledge exchange and joint innovation projects.
4.**Infrastructure, Resources, and Digital Ecosystem**	Invest in digital infrastructure (simulators, e-learning platforms, and digital laboratories), port modernization, and cyber security.	1. Upgrade port facilities with IoT and automation. 2. Implement secure digital communication systems. 3. Create regional cybersecurity frameworks. 4. Ensure access to up-to-date technology on ships and at training centers. 5.Coordinate cyber security policies to protect

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		maritime infrastructure
5.. **Monitoring, Evaluation, and Continuous Improvement**	Track progress and adapt policies.	1. Establish a regional maritime digital skills task force 2. Conduct regular assessments of skills development programs 3. Foster Lifelong Learning (Encourage ongoing professional development and adaptive learning platforms) 4. Share best practices and 5. Ensure regular feedback mechanisms for continuous policy refinement.

3.4 Asia-Pacific Region- Specific Recommendations & Focus Areas Format of the Paragraph

- **South Korea & Japan**
- Leverage advanced shipbuilding and technology R&D capabilities.
- Focus on autonomous ships, AI, and robotics.
- Enhance cyber resilience strategies.
- **China**
- Scale digital transformation in ports like Shanghai and Shenzhen.
- Promote digital skills in the large seafarer workforce.
- Develop domestic certification standards aligned with international norms.
- **Singapore & Malaysia**
- Act as regional digital innovation hubs.
- Foster innovative port initiatives and maritime digital ecosystems.
- Strengthen cybersecurity frameworks.
- **Philippines & Vietnam**
- Up skill large seafarer populations for digital competencies.
- Develop affordable, accessible training programs.
- Promote regional cooperation on seafarer welfare and certification.
- **Thailand & Australia**
- Focus on sustainable maritime practices with digital tools.
- Enhance cybersecurity and safety standards.
- Support regional research and development initiatives.

4. RECOMMENDATIONS

This section provides Strategic, Implementation, Modules and Training Program recommendations.

4.1 Common Strategic Recommendations

- *Harmonize Standards & Certifications-* Develop regional frameworks for digital competencies, mutual recognition, and portability of certifications.
- Strengthen Education & Training- Incorporate emerging tech modules into maritime curricula and also Promote online learning, simulators, and industry internships.
- *Promote Industry-Government Collaboration-* Foster public-private partnerships for innovation hubs and pilot projects and encourage shipping companies to invest in crew upskilling.
- *Focus on Soft Skills & Leadership-* Equip seafarers with adaptability, problem-solving, and leadership skills for tech-driven environments.
- *Invest in Infrastructure & Cybersecurity-* Modernize port and vessel digital infrastructure and Implement regional cybersecurity frameworks.

4.2 Implementation Recommendations

- Phased Rollout:- Pilot programs in key maritime hubs, followed by global expansion.
- Funding and Incentives: Grants, subsidies, and recognition for early adopters.
- Inclusion: Ensure training is accessible to seafarers from diverse backgrounds and regions.
- Collaboration with Industry: Leverage industry expertise and real-world scenarios.

These require a collaborative effort among **maritime authorities** for Policy oversight, certification standards, and funding. The **maritime education and Training Institutions** are responsible for curriculum development and delivery, as well as assessment. [13] **Shipping companies** should actively facilitate the on-the-job training and career development of seafarers,

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particularly those who must be passionate about training, acquire new skills, and pursue career advancement. **Table 3** summarizes the recommended action plan for implementing skills and policy alignment .[12], [13]

Table 3. Recommended Implementation Roadmap

SHORT TERM (1-2 years)		Policy harmonization, pilot projects, curriculum updates / establish regional task forces, initiate pilot training programs, update maritime curricula		
Phase	**Time Frame**	**Key Activities**	**Responsible Parties**	**Expected Outcomes**
1 Initiation	0-6 months	Establish a regional and national task force; conduct a needs assessment, and develop a curriculum outline.	Maritime authorities, industry bodies	Clear understanding of skill gaps and training needs.
2. Development	6-12 months	Develop training modules; Update curriculum and certification standards, and partner with training providers	Training institutions, Maritime academies, regulators and industry partners	Ready-to-implement training programs and standards
3. Implementation	12-24 months	Pilot training programs; launch online learning platforms, and integrate digital skills into certification	Maritime authorities, companies, and academies	Increased digital literacy and skills among seafarers
4. Evaluation & Expansion	24+ months	*Monitor* progress, gather *feedback* and scale successful programs	All stakeholders	Broader adoption, continuous improvement, and sustainable career pathway
MEDIUM TERM (3-5 years)		Expansion of training, infrastructure upgrades, certification standardization; Scale successful pilots, upgrade port and vessel digital infrastructure, and mutual recognition of certifications		
LONG TERM (5+ years)		Full integration, continuous innovation**, regional leadership;** Maintain adaptive policies, foster innovation hubs, lead global maritime digital standards		

4.3 Recommended Module and Training Program in the Era of Emerging Technologies

Objective: To prepare the maritime workforce for the future, ensuring safety, security, and operational excellence in the face of technological advancements.[11] Continuous review and stakeholder engagement are vital for its success. **Table 4** provides the contents of the modules for the training program .

Table 4 Module Contents for the Training Program

Modules	**Contents**
Module 1: Introduction to Digital Maritime Environment	Overview of **emerging technologies** (automation, AI, IoT, and digitalization etc.) in the maritime industry Its Impact on seafarer roles Its Impact on safety, efficiency, and environmental sustainability. Future industry trends and career opportunities
Module 2: Digital Skills and Technologies	Operating automated systems and ship management –software-Hands-on training on vessel automation

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	systems. Understanding IoT sensors and data collection Basics of cybersecurity for seafarers (Best practices for cybersecurity, data integrity, and incident response) Cyber hygiene and safe use of digital tools. Digital documentation and blockchain applications
Module 3: Maintenance and Troubleshooting of Digital Systems - -	Diagnosing issues in automation and control systems Routine maintenance of IoT devices Troubleshooting cybersecurity threats and emergency response procedures
Module 4: Data Analytics and Decision-Making	Introduction to Data Analysis Tools Basics of data collection, analysis, and visualization. Using data for safety, navigation, and efficiency Using data analytics for route planning, maintenance, and safety management. Case studies on data-driven decision-making
Module 5: Digital Communication and Documentation	Secure digital communication protocols. Electronic documentation, certificates, and blockchain applications.
Module 6: Soft Skills for the Digital Era	Change Management and adaptability Critical thinking, problem-solving, and innovation. Leadership and teamwork in technologically advanced environments.
Module 7: Career Pathways, Continuous Learning Development, and Certification	Access to online courses, webinars, and industry updates. Certification pathways aligned with international standards for advanced skills Opportunities in maritime digitalization, cybersecurity, and data science Mentoring, networking, and lifelong learning resources

Delivery Methods: E-learning modules and webinars, Simulator-based practical training, On-the-job digital competency assessments, and Industry workshops and seminars. [13]

5. CONCLUSIONS

Aligning seafarers' skills and policies with emerging technologies is crucial for the future resilience and competitiveness of the maritime industry. It requires a collaborative approach involving international standards, national policies, industry initiatives, and continuous education to equip seafarers with the capabilities needed in an increasingly digital and automated maritime environment. By fostering continuous learning, updating regulatory frameworks, and establishing clear career pathways, the maritime sector can attract, retain, and advance talented professionals who are prepared for the digital age.

On the other hand, aligning seafarers' skills and policies across these diverse nations requires a collaborative, flexible, and forward-looking approach. Emphasizing digital literacy, industry partnerships, and continuous professional development will ensure seafarers are prepared for the technological future, supporting career growth and maritime industry resilience.

The **Asia-Pacific region's maritime sector**, through APEC SEN, can capitalize on **emerging technologies** by developing a harmonized, inclusive, and forward-looking regional policy and training ecosystem. This approach will enhance safety, competitiveness, and sustainability, positioning the region as a global leader in maritime innovation.

For the Seafarers' Skills and Policy Alignment in an Era of Emerging Technologies, the implementation strategies and action plans can be summarized using the mnemonic **APEC SEN.** Mnemonic is a technique where a pattern of letters, ideas, or associations for example using **action verbs** assists us in remembering something**.**

Let us APEC SEN :

A – **Advance** the state-of-the-art training facilities, e-learning platforms, and existing training curricula to include digital modules.

P - **Promote** lifelong learning and up-skilling aligned with industry needs, and promote awareness campaigns on digital career opportunities.

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E – **Encourage** all Seafarers to acquire relevant digital skills for career advancement

C - **Collaborate** with maritime training institutions, industry players, and international bodies for skills development to create sustainable career pathways in the digital marine industry.

S - **Standardize** certification and qualification frameworks for emerging skills across countries by committing to integrating digital competencies into seafarer training and certification.

E – **Evaluate and monitor** the skill development outcomes regularly, in recognition of digital skills as integral to career advancement.

N- **Never give up** in supporting lifelong learning and recognizing new competencies for the continuous professional development, focusing on digital skills and emerging technologies, to enhance career progression opportunities for seafarers.

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THE EVALUATION OF THE WATER QUALITY OF TABACARIE'S LAKE

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Abstract : In the present paper, we will tackle the water quality problem in the lentic environment of one of the most well-known lakes in Constanta, Tăbăcărie. The pollution degree will be evaluated to identify the qualitative composition of the microbiota from the analysis sites, respectively, the chlorophyll indicator and the physical-chemical parameters (ammonium and phosphate ions, dissolved oxygen (DO), biochemical oxygen demand (BOD) and pH).
Key words : The lake, the lentic environment, microbiota, physical-chemical parameter.

1. INTRODUCTION

Urbanisation, overpopulation and pollution are problematic factors in the contamination of water, such as lakes in urban areas. Natural water becomes contaminated from pollutants that are brought by wind, rain, and human activities. A wide range of problems that cause lakes to become rich in nutrients have been reviewed, and both natural and anthropogenic factors cause this enrichment with nutrients. Many parameters, such as temperature, nitrogen content, DO, BOD, pH, conductivity, hardness, heavy metals and chlorine levels, can determine water quality. We consider the physico-chemical and biological aspects of aquatic ecosystems.

At the beginning of the project, we established the sampling areas of Tăbăcărie Lake:

a) First sampling point (SP1): near the bridge at the B'Arca restaurant, opposite the Ramada hotel;

b) Second sampling point (SP2): at the outflow into the Black Sea, near the Mamaia Exhibition Pavilion and the Constanta SUD Wastewater Treatment Plant;

c) Third sampling point (SP3): behind the stud farm within the Constanta Micro-Reserve, the Natural Sciences Museum Complex;

d) Fourth sampling point (SP4): in the reed bed area located between City Park Mall and the diving centre.

2. PHYSICAL-CHEMICAL METHODOLOGY AND DISCUSSIONS

We measured the following physical and chemical parameters: pH, temperature, ammonium ions $(NH_4)^+$, phosphate ions $(PO_4)^{-3}$, dissolved oxygen (DO) and biochemical oxygen demand (BOD).

pH (potential of hydrogen) helps us to identify the acidity or alkalinity of solutions on a scale from 1 to 14, where seven is neutral. In lentic sites, the pH value must be between 6.5 and 8.5. The samples were analysed with the pH-meter. Because the temperature can influence the pH levels and the oxygen concentration, we also measure this parameter. The measurements were made in situ with the help of a thermometer in °C.

The ammonium and phosphate ions were measured with the spectrophotometer Pharo 300. To determine the $(NH_4)^+$, the team added 5 mL of sample to a reaction cell containing hypochlorite ions to form monochloramine with the ammonium present. One dose of a substituted phenol was then added to produce a blue indophenol derivative. Due to the yellow colouration of the reagent blank, the final solution appeared yellow-green to green. For $(PO_4)^{-3}$ determination, orthophosphate ions in the sample reacted with molybdate ions in a sulfuric acid solution to form molybdophosphoric acid. This was subsequently reduced with ascorbic acid to generate phosphomolybdenum blue.

Figure 1 The Pharo 300 spectrophotometer

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In the case of dissolved oxygen (DO), in the field, 2 mL of 40% manganese (II) sulphate and alkaline potassium iodide were added to fix the oxygen in each sample. In the lab, 10 mL of supernatant was treated with 5 mL sulfuric acid (1:3), which was then titrated with 0.1 N thiosulfate. DO was expressed in mg O_2/L. The BOD is the amount of oxygen consumed by microorganisms in the water over 5 days. It is determined by the difference between the amount of DO found in the water sample immediately after collection and after 5 days of incubation at 20°C. Both determinations of oxygen quantity were done by the Winckler method.

Figure 2 Dissolved oxygen determination

The results for the analysed physico-chemical parameters are presented in Tables 1-6.

Table 1. pH levels

pH	November	March	April
SP 1	8.41	8.36	8.48
SP 2	8.42	8.35	8.41
SP 3	7.24	8.36	8.44
SP 4	8.14	8.31	8.3

The pH values are within legal limits. However, the data shows that the water from Tabacarie lake is weakly alkaline, a typical trait of the Dobrujan waters.

Table 2. Temperature values

Temperature	November	March	April
SP 1	8	12	17
SP 2	8	13	18
SP 3	8	13	30
SP 4	8	12	30

Recorded temperatures matched seasonal trends, except at SP 3 and 4 in April, where unusually high values suggest a possible warm water discharge from the microreservation, though further analysis is needed.

Table 3. Ammonium ion concentrations

$(NH_4)^+$	November	March	April
SP 1	1.12	2.26	1.92
SP 2	8	2.04	1.08
SP 3	6.12	2.06	2.68
SP 4	1.38	2.46	0.37

Table 4. Phosphate ion concentrations

$(PO_4)^{-3}$	November	March	April
SP 1	0.05	0.05	2.17
SP 2	0.05	0.03	3.98
SP 3	0.38	0.04	3.62
SP 4	0.05	0.05	1.16

Eutrophication indicators varied significantly between SP and across different months. Ammonium concentrations were generally consistent with water quality classes III and IV, with an average of about 1.8 mg N-NH_4^+/L, except at SP 2 and 3 in November, where higher values of 8 and 6 mg/L were recorded. Phosphate supports plant growth but can cause eutrophication above 0.3 mg/L. In November and March, levels were low (avg. 0.045 mg P/L, class I), but rose sharply in April, over 0.9 mg P/L and nearly 4 mg/L at peak, classifying the lake as hypertrophic.

Table 5. DO content

DO	November	March	April
SP 1	4.58	12.93	12.58
SP 2	5.11	13.50	11.94
SP 3	5.11	12.37	12.86
SP 4	5.90	12.47	13.08

Table 6. BOD values

BOD	November	March	April
SP 1	2.85	6.19	9.49
SP 2	0.27	8.41	10.24
SP 3	5.11	11.52	12.86
SP 4	5.34	10.18	12.80

Dissolved oxygen in the lake was low in November (5.175 mg O_2/L, class III), but doubled by March–April, improving to class I. BOD was low in November (3.4 mg O_2/L, class I) and rose sharply in April (11.34 mg O_2/L, class IV), indicating increased organic load and reduced water quality. From the DO and BOD values, we can say that the lake is in a low eutrophic

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state, as the DO concentration is greater than 9, and the high values of BOD in the spring months tell us about the presence of microorganisms that consume the said oxygen.

These criteria are in close connection with the biological aspect of the paper.

3. BIOLOGICAL METHODOLOGY AND DISCUSSIONS

The biological analysis aimed at determining chlorophyll as an indicator of algal biomass, using fluorescence methods applied to microalgae, including cyanobacteria. Monitoring biological (algal) parameters in different seasons is necessary to cover the widest possible range of algal species, depending on their optimal development.

LUGOL solution (1:1) was used for sample pigmentation; 4 mL of the water sample and 1 mL of LUGOL solution were added, followed by vortexing the mixture. The sample was left to react for 10 minutes, then analysed through optical microscopy.

Acridine orange dye was used for epifluorescent microscopic analysis. The sample was prepared by adding 100 µL of dye per mL of suspension. The mixture was homogenised and then filtered through a 0.22 µm Millipore filter using a holder device. Staining was performed for a minimum of 10 minutes, after which the sample was evaluated under a microscope with epifluorescent illumination, using a blue filter.

Chlorophyll contents were quantified with the help of the FluoroProbe III device (produced by BBE-Moldaenke, Germany). The chlorophyll contents are expected from a variety of microalgae, including cyanobacteria (1). In Figure 3, the chlorophyll to depth ratio is represented.

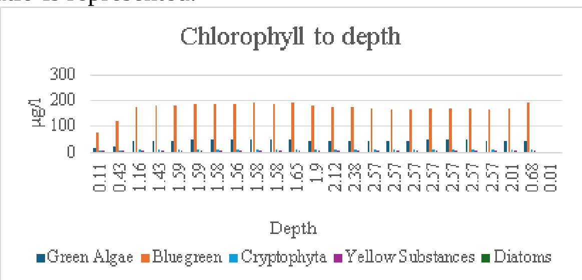

Figure 1 Chlorophyll to depth ratio

One of the most predominant cyanobacteria found by us in Tăbăcărie's Lake is *Microcystis* sp. (Figure 5). This bacterium feeds on high concentrations of nitrogen, phosphorus, and carbon. Therefore, it can be used as a bio-indicator for the eutrophication level of bodies of water. As it is represented in Figure 3 and 5, we can see a high density of these bacteria in the water. These cyanobacteria were found in all three months, along with *Oscillatoria* sp., *Chroococcus* sp. and *Scenedesmus* sp., other nitrogen and carbon-rich water-loving bacteria and algae. Both Figure 6 and 7 are from November, and the chlorophyll graph was made in March; the continuity of cyanobacteria was noticed until April.

Figure 4 Microcystis sp .

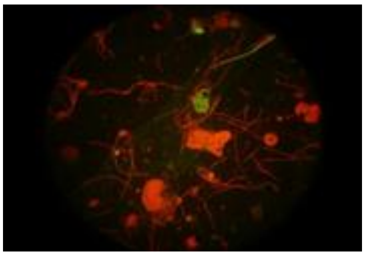

Figure 5 Epifluorescent microscopic analysis

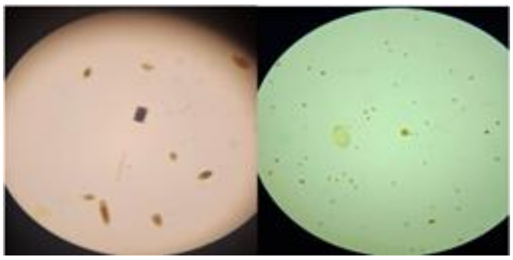

Figure 6 Two samples from SP3 (March)

In Figure 6, the presence of *Scenedesmus* sp., *Pediastrum* sp., *Rhizosolenia* sp., *Melosira* sp. and *Asterioneala* sp. can be noticed. The former two are algae which thrive in nitrogen-filled waters (2), and the latter three are diatoms which are stenobionts; they are very sensitive to changes, which makes them good bio-indicators in aquatic ecosystems.

It has been observed that in March, *Paramecium* sp. and other microorganisms such as diatoms have started to appear (Figure 6 and Figure 7). *Paramecium* is a ciliate that feeds on algae, yeast, and other bacteria. Their presence suggests a high amount of algae to feed on (Figure 8), including cyanobacteria, which is a known lover of enriched waters. In the same picture, we can also remark the presence of *Microcystis* sp.. As soon as April, we noticed the lack of diatoms in the samples, and we correlated this with the increase in $(PO_4)^{-3}$ and the decrease in $(NH_4)^{+}$.

Figure 7 Sample dominated by *Paramecium* sp.

4. CONCLUSIONS

From the point of view of the analysed physical-chemical parameters, it can be said that, for the time considered, all the analysed parameters were within normal limits, except for the phosphate ion concentrations in April, which suggests the hypertrophicity of the lake.

From all the data we have collected so far, we can deduce that Tăbăcărie's Lake has a Quality Class IV (5), after analysing the ion concentration. The presence of cyanobacteria is in direct correspondence with ion concentration. Especially SP2 and SP3, which are the more polluted zones of the lake. In SP2, water is directly spilt in the lake from the Wastewater Treatment Plant, and in SP3, water is discharged from the horse stud and other enclosures from the micro reservation. This enrichment can be directly seen from the chemical and biological research, and from the green colouration of the lake, mainly in SP3. However, more analysing needs to be done, which involves collecting and analysing data to maintain a proper monitoring process in this area.

5. ACKNOWLEDGMENTS

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ENERGY EFFICIENCY STRATEGIES FOR OFFSHORE VESSELS WITH DYNAMIC POSITIONING SYSTEMS

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Abstract: The maritime and offshore sectors are under increasing pressure to reduce greenhouse gas (GHG) emissions in line with European Union regulations. Starting from January 2025, the revised EU Monitoring, Reporting, and Verification (MRV) framework extends its scope to offshore vessels above 400 Gross Tonnage. In this context, energy efficiency has come increasingly into focus of operational team of offshore vessels equipped with Dynamic Positioning (DP) systems. Aiming to identify the strategies to optimise fuel consumption and to improve energy efficiency in DP operations, the authors adopted a simulation-based approach using Kongsberg K-POS simulator. This research study analyses the performance of a DP-equipped vessel under varying environmental conditions, system settings, and operational modes. The results highlight several practical pathways for reducing energy consumption: lower gain, the use of green mode, and the optimisation of vessel heading relative to external forces. The conclusions confirm that strategic adjustments to DP system parameters and vessel orientation can yield meaningful reductions in fuel consumption and emissions, thereby lowering operational costs and supporting compliance with EU MRV requirements. This research demonstrates the utility of simulator-based analysis in evaluating energy efficiency strategies and provides practical insights for offshore operators seeking to improve sustainability and compliance to EU regulations.
Key words: dynamic positioning; energy efficiency; fuel consumption; greenhouse gas emissions; offshore vessels; simulations.

1. INTRODUCTION

Industries worldwide are under regulatory, economic, and environmental pressures to promote and drive sustainability objectives. One of the most pressing challenges for maritime industry and offshore operators is the reduction of greenhouse gas (GHG) emissions. The International Maritime Organization (IMO) has introduced several initiatives, such as the Energy Efficiency Design Index (EEDI) and the Carbon Intensity Indicator (CII), aimed at improving energy performance across the global fleet [1],[2],[3]. In parallel, the European Union has strengthened its Monitoring, Reporting, and Verification (MRV) Regulation [4],[5], requiring companies to submit GHG emissions report through EMSA portal [6]. As of 1 January 2025, the revised MRV framework extends its scope to include offshore vessels and general cargo ships above 400 GT, irrespective of flag or registration state [7]. This regulation obliges vessels to monitor, report, and verify emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), in addition to collecting operational data such as transported cargo, distance travelled, and time spent at sea [8].

Against this backdrop, energy efficiency has come increasingly into focus for offshore vessels equipped with Dynamic Positioning (DP) systems. While DP technology is indispensable for operations requiring precise station-keeping - such as offshore drilling, subsea construction, or wind farm installation - it is inherently energy-intensive. Maintaining a fixed position under the influence of wind, current, and waves demands continuous use of thrusters and generators, often leading to substantial fuel consumption and associated emissions. Thus, identifying strategies to optimise DP operations has become a central theme in both academic research and industry practice [9].

The purpose of this paper is to investigate and evaluate energy efficiency strategies for offshore vessels using Dynamic Positioning systems. The study employs a simulation-based methodology using the Kongsberg K-POS simulator, one of the most advanced DP training and research platforms available [10]. This approach allows for controlled experimentation under varying environmental conditions, operational modes, and system configurations, without the costs or risks associated with full-scale sea trials.

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Beyond the technical adjustments of DP system parameters, it is equally important to recognise the role of DP operator behaviour in shaping energy efficiency outcomes. While operational strategies are designed to limit power demand, fuel consumption, and emissions, their effectiveness ultimately depends on how they are applied in practice. Encouraging sustainable decision-making must therefore begin during simulator-based training, where operators can develop awareness of energy-efficient practices, and continue through consistent application on board vessels. In this way, technological solutions and human behaviour act in synergy to achieve meaningful improvements in efficiency and compliance with regulatory requirements.

The research design focused on three primary variables: (1) adjustment of gain settings, which influence the responsiveness of thrusters; (2) use of different DP operational modes (high precision, relaxed, and green); and (3) the vessel's heading relative to external forces such as wind and current. Through systematic variation of these parameters, the study emphasizes practical measures that reduce fuel consumption, and, consequently, greenhouse gas emissions.

2. METHODOLOGY

The methodology employed a simulation-based approach to analyse the energy efficiency of offshore vessels equipped with Dynamic Positioning (DP) systems. The study was conducted using the Kongsberg K-POS simulator, which provides a realistic operational environment for testing vessel performance under controlled conditions.

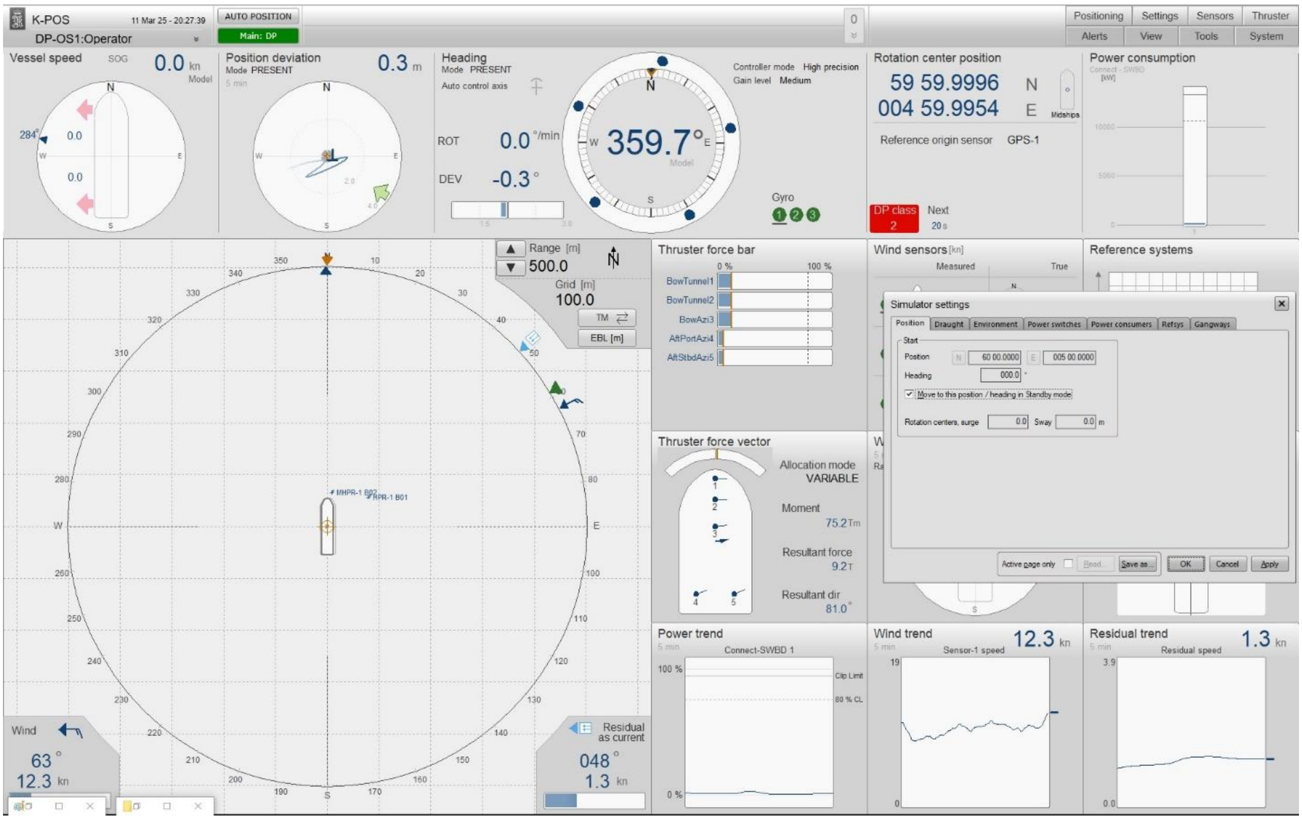

Figure 1 DP Kongsberg K-POS system interface

2.1 Simulation environment

The simulated DP vessel configuration comprises two bow tunnel thrusters, one azimuth thruster at the midship, and two azimuth thrusters at the stern. The control and monitoring display of the DP Kongsberg K-POS (Figure 1) integrates several key operational parameters, including the vessel's longitudinal and lateral speeds (ahead/astern and port/starboard), the real-time deviation from the reference position, and gyro data such as heading, rate of turn, and active gyro sensors. The interface also shows the coordinates of the vessel's centre of rotation, which can be adjusted according to the operator's preferences. The power is supplied by seven diesel-electric generators, monitored in real time through the simulator's Power Management System (PMS). The system allows tracking of energy production, distribution, and thruster load under different operational scenarios [11]. To replicate realistic offshore operations, the following baseline conditions were introduced: wind: 10 kN from 60°, current: 1 kN from 45°, wave height: 1 m from 60° with a 4 s period. These values were later varied to assess system behaviour under increasing external forces.

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2.2 Operational parameters tested

The methodology includes systematic variation of three sets of variables: gain, DP control modes, and heading, as well as the observation of the performance metrics: total power demand (kW), fuel consumption implications, positional deviation (m) relative to the set point, and capability limits of the vessel under different environmental forces.

2.3 Data analysis

Data were collected from simulator logs and visual interfaces (PostPlot, PMS, and capability plots). The analysis focused on evaluation of energy consumption trends across different configurations, with particular attention to energy savings from reduced gain and "Green" mode, the trade-off between precision and fuel efficiency, and the impact of vessel heading on thruster demand.

3. RESULTS AND ANALYSIS

The simulations conducted on the Kongsberg K-POS platform provide insights into how Dynamic Positioning (DP) operations can be optimised for improved energy efficiency. The results are structured according to the main parameters tested, with references to the simulator's graphical outputs.

3.1 Baseline DP Operation

To analyse the vessel's behaviour in Dynamic Positioning mode, the following external conditions have been introduced in the simulator: wind of 10 kN from 60°, current of 1 kN from 45°, and waves of 1 m from 60° with a period of 4 seconds. These values are variable, to make the simulation as close to reality as possible. The vessel is set in DP mode, maintaining position as shown at the top of the figure, with speed at 0 kN, deviation from the set point of 0.3 m, and the system constantly adjusting to keep deviation as close to zero as possible. The vessel's heading was set at 0°.

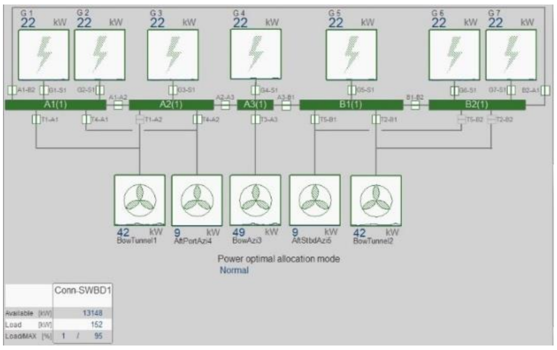

Figure 2 DP Power Management System

The Power Management System comprises seven diesel-electric generators (G1–G7) with an interface that allow real-time monitoring of the kW output of each generator. They are connected to a single distribution board (for simplicity in this simulator configuration). However, in DP2 or DP3 class operations, redundancy requires two distribution boards, reducing the risk of losing all thrusters simultaneously and enabling the vessel to maintain position in case of system failures. From the distribution board, power is supplied to the thrusters, displayed at the bottom of the figure, with their real-time kW consumption. Next to it, the additional data shows 13,148 kW as total generation capacity and 152 kW as the current load.

The DP system uses an algorithm to calculate the vessel's station-keeping limits for headings between 0°–359°, accounting for external forces. This is emphasised in the capability plot (Figure 3). At the centre, the blue contour diagram represents maximum wind forces the vessel can withstand while maintaining position for each heading. At the lower side, 56.6 kN is shown as the maximum wind speed the vessel can resist at 0° heading. The plot demonstrates that a heading near 60° is far more favourable than 0°, enabling position-keeping with lower energy consumption. Under stronger wind forces, the vessel could maintain position at winds up to approximately 130 kN when heading 60°.

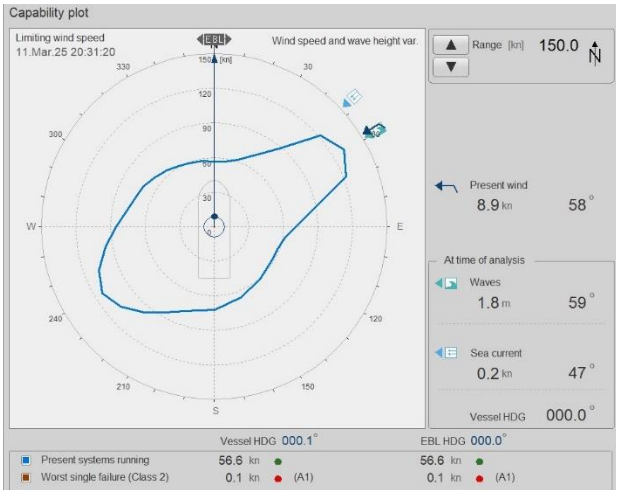

Figure 3 Capability Plot

The Capability plot also includes the "Worst single failure" condition. Although not applicable in this single-board configuration, in a dual-board setup this value would show the maximum wind under which the vessel can still maintain position after losing the most critical board and thrusters. In this case, however, the loss of the only distribution board would disable all thrusters, meaning a mere 0.1 kN wind would be enough to cause loss of position and drifting.

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As external forces intensified (wind 25 kN, current 1.3 kN), thruster demand grew substantially, raising generator load to 698 kW (Figure 4).

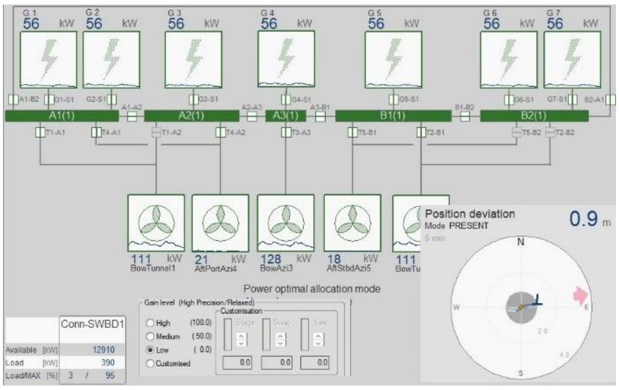

Figure 4 Increase of external forces

This directly linked fuel consumption to environmental conditions, underscoring the importance of adaptive operational strategies.

3.2 Adjust of gain settings

A parameter that directly affects fuel consumption is gain adjustment. Gain determines the “aggressiveness” of thrusters in position-keeping, with four settings: high, medium, low, and custom (user-defined percentages for surge, sway, and yaw).

- High gain provides the most precise station-keeping but at the cost of maximum fuel use.
- Medium and low settings reduce thruster workload and fuel consumption, though with larger positional deviations.

Thus, gain selection must balance required accuracy with weather conditions; high gain is not recommended in calm seas as it unnecessarily increases fuel use.

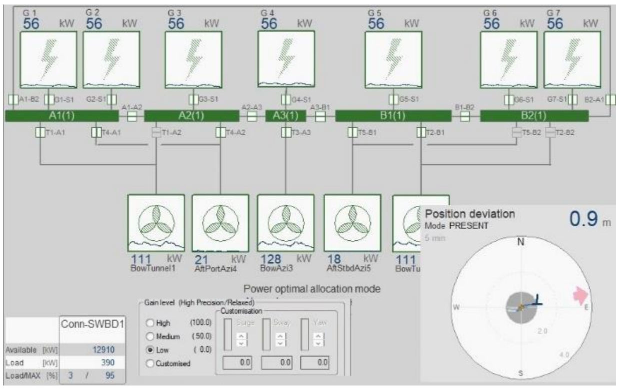

Figure 5 Low gain

Figure 5 shows energy demand under low gain, reduced to 390 kW compared with 698 kW at medium gain, but with deviation increasing to 0.9 m.

3.3 DP Control Modes: High precision, Relaxed, and Green

Although “High precision” mode is the most common DP control setting, some systems include “Relaxed” and “Green” modes designed to reduce energy consumption and equipment wear.

In “Relaxed” mode, the vessel maintains position within an operator-defined circular zone rather than a fixed point. While this reduces thruster demand, the vessel may leave the zone temporarily before DP commands higher thrust to re-enter. This mode is suited to calm conditions.

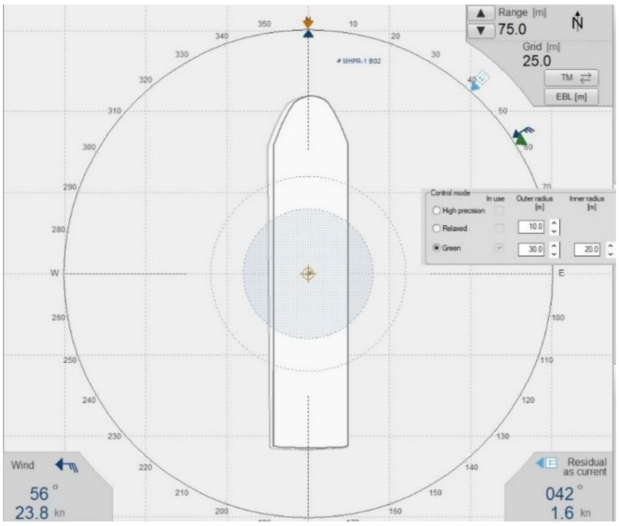

Figure 6 “Green” mode

The “Green” mode, shown in Figure 6, is more advanced. It uses predictive algorithms to minimise thruster operation while keeping the vessel inside a predefined zone between an inner and outer circle. It is more energy-efficient than “High precision” and more accurate than “Relaxed” mode. This makes it applicable in a broader range of operating conditions. Figure 7 illustrates reduced load under “Green” mode: 580 kW compared to 698 kW in High precision”, both at medium gain.

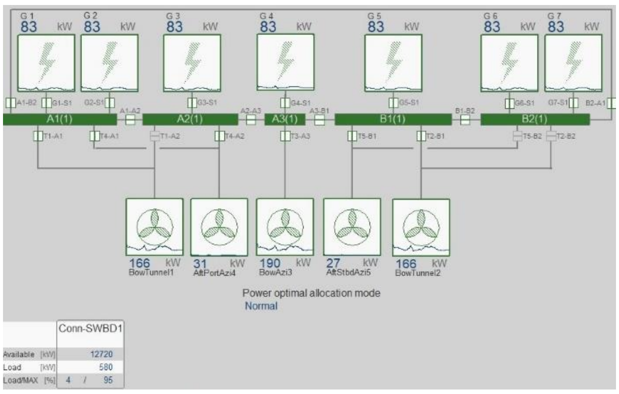

Figure 7 Energy consumption in “Green” mode

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3.4 Change of heading

Another critical factor for fuel consumption is vessel heading. As indicated in the capability plot (Figure 3), energy demand is significantly affected by orientation relative to wind and current. When positioned with the bow into prevailing forces, exposed surface areas are reduced, lowering resistance. Figure 8 shows vessel heading adjusted to 61°.

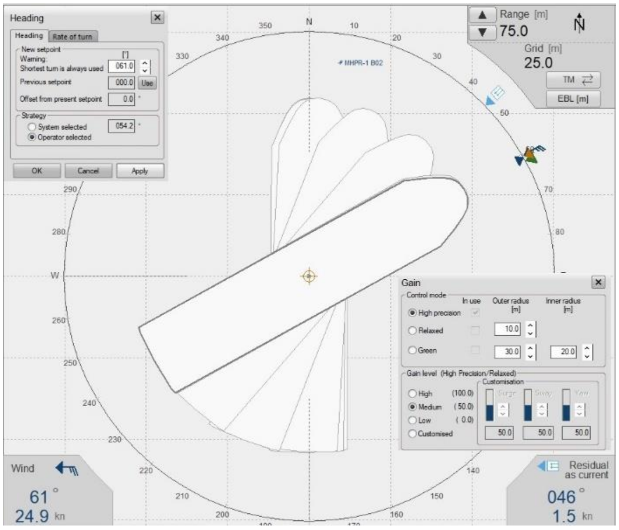

Figure 8 Change of Heading

Figure 9 confirms the efficiency gain: power demand dropped from 698 kW at 0° heading to 36 kW at 61°, both at medium gain. This demonstrates substantial fuel savings. Heading optimisation is therefore essential in DP operations, within the limits of operational safety and mission requirements.

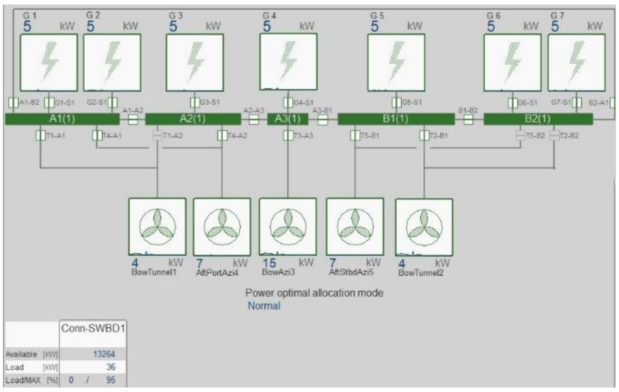

Figure 9 Energy Consumption at 61° Heading

4. DISCUSSION

The simulations clearly demonstrated that three operational strategies have the greatest impact on improving energy efficiency during DP operations:

Gain adjustment – Lowering gain settings (from medium to low) reduced overall power demand from 698 kW to 390 kW, albeit with a modest increase in positional deviation (0.9 m). This illustrates the trade-off between accuracy and efficiency: in calm environmental conditions, a less aggressive gain setting can deliver significant fuel savings without compromising operational safety.

Control mode selection – Employing alternative DP modes such as green or relaxed significantly reduced thruster activity compared to the default high precision mode. The green mode, in particular, achieved a reduction from 698 kW to 580 kW while maintaining acceptable accuracy. These findings suggest that operators can achieve meaningful fuel savings by tailoring DP mode selection to operational requirements, especially in standby or low-risk conditions where absolute positional accuracy is not mandatory.

Heading optimisation – Adjusting vessel orientation relative to wind and current produced the most substantial energy savings. For example, changing heading from 0° to 61° reduced power demand from 698 kW to only 36 kW. This highlights the critical role of navigational planning in minimising thruster workload. Heading optimisation should therefore be considered a primary strategy whenever safety and operational constraints allow, as it can reduce both fuel consumption and emissions by an order of magnitude.

Together, these strategies demonstrate the potential for operational decision-making to substantially reduce fuel consumption and associated greenhouse gas emissions in DP operations. Importantly, the study shows that such reductions do not necessarily require costly retrofits or new technologies, but can be achieved through informed adjustments to existing DP system parameters. This provides practical guidance for offshore operators seeking to comply with the extended EU MRV regulation

5. CONCLUSIONS

The analysis conducted on the Kongsberg K-POS simulator identified several methods that can significantly contribute to reducing fuel consumption in Dynamic Positioning (DP) operations. Each factor studied had a measurable impact on the vessel's energy efficiency, and the findings provide practical solutions for optimising fuel use in offshore activities.

First, gain adjustment proved essential in reducing energy demand. Using a lower gain setting, such as Low Gain, resulted in a significant decrease in thruster load, leading to lower fuel consumption. While this adjustment may increase positional deviation, under favourable weather conditions the compromise is acceptable given the benefits of reduced energy use.

Second, the activation of the "Green" mode delivered notable energy savings without substantially compromising station-keeping accuracy. In this mode,

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the DP system applies predictive algorithms to minimise thruster activity, making it far more efficient than the standard high precision mode. This is especially valuable in calm operational environments, where the vessel is not exposed to high external forces such as strong wind or current.

Another critical finding was the influence of vessel heading on fuel consumption. Adjusting the vessel's orientation relative to wind and current had a major impact on energy efficiency. This emphasises the importance of selecting an optimised heading that minimises thruster load and enables substantial energy savings.

In terms of power management, careful monitoring of each thruster and balanced distribution of load across the generators improved the efficiency of the DP system. Load on the distribution board varied according to external conditions, and by adjusting system parameters such as gain settings and control modes, total fuel consumption was significantly reduced without compromising the vessel's essential performance.

In conclusion, by implementing targeted fuel-saving strategies - adjusting DP control parameters, using more energy-efficient modes, and selecting favourable headings relative to environmental conditions - it is possible to achieve meaningful reductions in energy consumption. These measures not only lower operational costs but also support environmental protection by reducing CO_2 emissions.

Ultimately, achieving lasting improvements in fuel efficiency and emissions reduction requires not only technical optimisation but also behavioural change, with sustainability becoming an integral part of operator decision-making and maritime practice.

However, the study is limited by its reliance on simulation data, and future research should validate these findings through full-scale trials under real offshore operational conditions to further refine energy efficiency strategies.

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APPLICATION OF RKFMEA, FOR ASSESSING THE RISK AND SUSTAINABILITY IN THE BLACK SEA BASIN

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Abstract: The Black Sea basin is a territory that is distributed between countries with different status and level of economic and social development, in which various historical, cultural and social transformations have been and continue to be realized, in which challenges and risks of a different nature are encountered. Nowadays the territory around the Black Sea is identified as the "Black Sea Region". That is the reason for which it is important to create models through which various risks are managed - economic, social, natural, technological. The research is aimed at preventing natural and technological risks in coastal zones and the water area, as a prerequisite for sustainable development, associated with the ever-complicating technical and technological processes. The development proposes the use of specialized software for risk assessment and analysis and prevention management, the application of which creates a prospect for safer socio-economic development and sustainable growth and the assets we assess and seek to improve.
Key words : Black Sea basin, risk assessment, sustainability, FMEA.

1. INTRODUCTION

The Black Sea Basin is a territory that is distributed between countries with different status and level of economic and social development, in which various historical, cultural and social transformations have been and continue to be realized, in which challenges and risks of a different nature are encountered. Focusing on the risk as a starting point, or the possibility of an adverse event with damage occurring, the understanding of sustainable development is the presence and accumulation of knowledge for better management and avoidance or reduction of damage in the event of an adverse event. Or Risk Assessment + Selection and implementation of prevention + Periodic monitoring and renewal, which with good management give Sustainable Development [1].

2. MATERIALS AND METHODS

For the scientific assessment of the risk in the Black Sea basin had been used specifically designed risk assessment method called RkFMEA. The basic principle of RkFMEA, which is a management system, is that it is not based on the prevailing top-down approach, but on the bottom-up approach to data collection, risk assessment and planning of prevention measures and their management. The system takes into account the resources needed for prevention and this is reflected in the acronym. The system works on the basis of the expert opinion of specialists and responsible administrators at the selected lowest administrative level. The system is an extension and modification of FMEA [2] and uses a standardized set of quantitative factors with values from 1 to 10. It has been added to it, and on the same functional principle, more important factors for risk assessment and prevention management - that of the effect of existing protection and prevention measures and their effect (N) and of the proposed new prevention measures and their effect and efficiency (F) [3]. Depending on the selected lowest and basic administrative level that will assess and enter the data, two other factors are added to harmonize the risk levels and compare them under comparable conditions - the factor (L) for the value of possible damages from the GDP of the municipality or mayoralty or settlement, depending on the selected lowest administrative level and the factor (D) for the age dependency coefficient of this administrative level.

RkFMEA provides quantitative indicators and respectively comparable measurements of the risk level (risk priority number, RPN), including the current measures and activities for control and prevention (N) and in addition provides the complex risk factor (RPNF),

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representing the level of risk with the need for investment in prevention, the harmonized (normalized) risk levels according to the wealth of the community (RPNL) and according to its age characteristics (RPND). The system and the developed application are used to assess and plan investments in measures and activities for the prevention of accidents and catastrophes, monitoring their implementation and effect, reports and reporting with various analyses with sections through the collected base and with the most useful tool for management, which is an analysis of trends and changes in risk levels and complex and harmonized risk factors, especially for the need for prevention.

The threat and risk are always spatially localized. The system and application allow this to be the threat and risk zone, determined by direct delineation by the expert or using databases, or described verbally, but localized for a city hall, municipality or other administrative level or directly by selecting a city hall or municipality. Subsequent integration is done for a higher level – municipality, or district and up. The delineation of a zone, while using the risk software RkFMEA is shown in Figure 1.

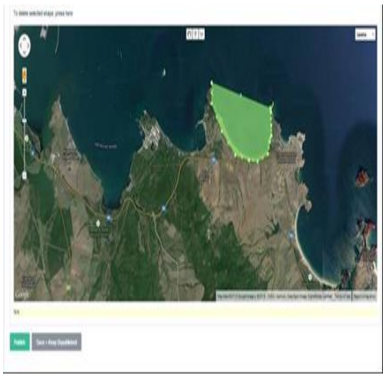

Figure 1 Delineation of a zone, RkFMEA

The RkFMEA system and the application work with a selection of factors from tables, descriptions in text format and an assessment of damage and prevention in an approximate monetary value, term in years or percentage. To derive the value of the factor (F) for the efficiency of a new prevention, which is done automatically, it is necessary to estimate the possible damage for the selected area or municipality, roughly in order. Intangible damage such as that for the environment in the system is estimated in the years needed to restore the affected area. Accordingly, the value of prevention is estimated in monetary means (money) and for the environment in years of recovery in the event of a disaster with implemented prevention. This approach, applied for the first time in the RkFMEA system, makes it possible to derive the efficiency of a given new prevention measure, and the complex risk factor RPNF shows how urgent a given new prevention measure is. The application allows for proposing and comparing several measures and choosing the most appropriate one in terms of its effectiveness, while the RPNF-based maps show where the proposed prevention measures are most urgent, taking into account the level of risk.

The risk levels and depictions, based on RPN are:

- High for a factor above 250 - ;
- Moderate for a factor from 50 to 250 -
- Low or negligible for a factor below 50 -

The risk levels based on RPNF, RPNL and RPND are:

- High for a factor above 1700-;
- Moderate for a factor from 200 to 1700-;
- Low or negligible for a factor below 200- .

The system and the application provide reports in tabular format and in GIS. For the purposes of planning and managing risk-based prevention and making investment and priority decisions at the municipal and district levels and above, the three-color maps are most suitable, while for detailing the measures themselves, specialized information for the administration in tabular form is suitable. Access to the summarized GIS information is offered to the public.

After extensive research and testing in administrations, the system and application only need a few hours once a year to fill in the data, which is sufficient to collect data and to output sufficient information for making management decisions. Figure 2 shows the trend of human health risk for all threats in Burgas district (simulated data), with a negative change in red, no change in yellow and a positive change in green, which means that new prevention measures have been implemented compared to the previous year and they are having an effect.

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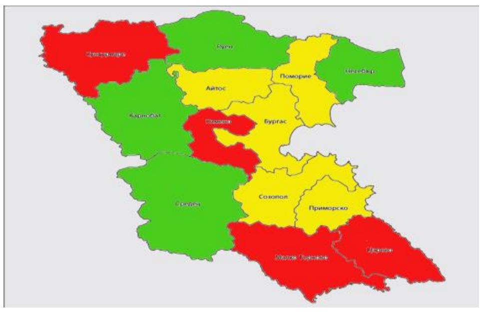

Figure 2 Delineation of risk zones within a municipality, RkFMEA

Figure 2 shows the trend of the risk to human health for all threats in the Burgas district (simulated data), with a negative change in red, no change in yellow and a positive change in green, which means that new prevention measures have been implemented compared to the previous year and they are effective.

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The developed application, accessible from a desktop computer, tablet or smartphone, was experimentally used for the risks of pollution of the Black Sea with petroleum products, with a detailed selection of the area and for the environmental and technological risks to human health for the Burgas district, with a selection of the municipality.

3. EXPERIEMENT

Using the risk assessment tool RkFMEA, the environmental and technological threats and risks to human health for the Burgas region, including the Yambol and Haskovo regions, have been identified based on a review of past events and surveys conducted with interested administrations [4]. The information had been gathered within a project funded within JOP Black Sea basin IUCRISKMAN, 2.2.1.73194.264.[5]

The main threats or "risks", according to our broad linguistic understanding of the meaning of the word risk, indicated by the survey participants focus on the pollution of the Black Sea waters with oil products. They are as follows, and their percentage weights were also derived from the study: Spill of pollutants from shipping – 45%, spill of pollutants from point sources on land – 18%, spill of pollutants brought by rivers – 19%, spill of pollutants from point sources at sea – 2%. The total amount is not 100% because permanent natural sources of hydrocarbon pollution are not included here. The main threats for the purposes of further systematization are detailed in three levels, with a priority given here for those from shipping: Spill from a ship in the open sea in the event of a collision, damage, catastrophe – 29%; Spill from a ship at anchor/in port from an accident or operation (this includes bunkering, bilge water, transhipment operations, waste) – 32%; Permitted and unregulated discharge of bilge water and pollutants from a ship on the high seas – 39%.

Threats from pollution of the Black Sea lead to risks that have been identified and assessed for the coastal environment, with permanent damage on land; the marine environment, with permanent damage at sea; fisheries and aquaculture; public health and tourism/beaches/industry (including agriculture and port industry).

After selecting an area, selecting a threat, sub-threat, risk, the factors and the descriptive part are determined, which are systematically managed by the application. The expert, working with the software selects, based on experience and knowledge, the corresponding value of the RPN factors, and it is important to consider whether the respective factor is in the green zone (value 1 to 3), the yellow zone (value 4 to 6) or the red zone (value 7 to 10).[6], [7], [8] To assist in the selection of the respective threat and risk, auxiliary tables have been developed. In addition, an estimate of the value of the possible damages is given. The example, given in Table 1 is from a sample from the table for selecting the effect of existing prevention - factor N. Even if a preventive measure is available, in the absence of support it is not effective, or will have a value of 8.

Table 1. Effect of the prevention factor N

Effect of the precaution measure or action	Description of its effect	Value
Absolute absence	Absolutely no precaution measure, control or action currently envisaged	10
Extremely low	Extremely ineffective or unproven distant measures or actions to prevent or avoid damage and casualties or unmaintained facilities or other safe measures.	8
Average	Average effect of the measure or action to prevent damage and casualties	6
Very high	Very high degree of certainty that the safeguard or action will prevent damage, damage and losses from occurring	2

The system and the application calculate the corresponding values for RPN, RPNF, RPNL and RPND.

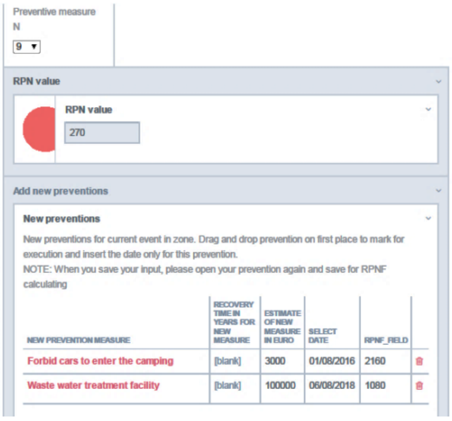

Figure 3 RPN, RPNF and proposed new measures Camping Garden

The value of F is determined by the ratio of the values for the possible damages and the costs of the new prevention measure. In the case of time values, this is again the ratio between the two. The dependence is not linear, with the greater effect of the new preventive measure being given priority.

The most effective one has a factor of 10 or a red zone to show the urgency of its implementation. The

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following Figure 3 is shown a screenshot of the application for the threat of pollution with petroleum products and the risk to tourism for the example of the dumping of car oils in the Gradina campsite (simulated data).

The cheaper measure is more effective and has a higher RPNF value and is in the red zone. The following year it was implemented and the risk level was already in the yellow zone, and with the remaining proposed measure the RPNF is only in the yellow zone with a value of 600, which suggests that it does not need to be implemented yet (Figure 4).

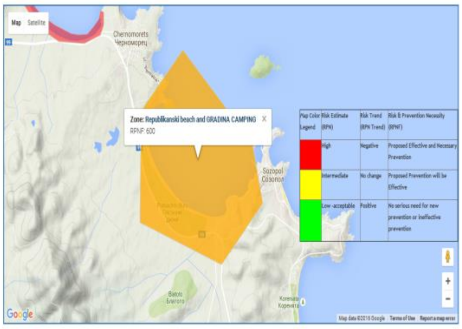

Figure 4 Next (after the risk assessment) year's RPNF Garden Camping Area

The system with the application clearly shows the effect of the implemented prevention, and also provides the opportunity to plan wisely and for preventive measures to be effective. Continuous annual monitoring and updating of data allows for effective planning and monitoring of implementation and to apply preventive measures according to the need and available resources.

3. CONCLUSIONS

The generalization for the entire region, when data is submitted by all interested parties and administrations, allows for comparison and for directing resources and funds to the most urgent places.

Planning preventive measures after risk analysis must also take into account the population's ability to cope with the possible consequences of a natural event or technological crisis. Comparing only the RPN risk levels, for example, for municipalities in one area does not always show where the risk is most significant in relation to the population in a given municipality. With the same damage, but with a different demographic structure, some municipalities will cope more easily than others, or the risk will be different for them.

Research and interviews with representatives of municipalities show the need to consider risk and prevention according to the needs and capabilities of the population in a given administrative unit. The application RkFMEA provides this opportunity for data collection and risk analysis and prevention management at the municipal level, with the territorial boundaries of the municipality conditionally corresponding to the zone indicated above.

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HOW TO ADDRESS THE CHALLENGES IN THE BLACK SEA REGION IN THE CONTEXT OF THE DEVELOPMENT OF THE BLUE ECONOMY

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Abstract *:* The publication examines the challenges facing the countries of the Black Sea region and the key role of human resources in the development of the blue economy, analyses how they can be effectively adapted to the new realities related to technologies, skills and policies. The data are based on our own researches, the reports and discussions of the annual National Round Table "The Sea - Border or Door". They show how the challenges can be addressed in order to improve cooperation processes, ensure citizen participation in management processes, increase knowledge about marine resources and accelerate the process of blue growth in the region.

Key words *:* Blue economy, challenge, cooperation, human capital, innovation, knowledge, renewable energy, skills, maritime professions, sustainable development, sustainable growth, technology.

1. INTRODUCTION

In the context of growing awareness of sustainable development and the need to utilize water resources in an economically and environmentally responsible manner, the blue economy and blue growth are emerging as key drivers for future development. These concepts cover a wide range of activities – from maritime transport and fishing to renewable ocean energy and tourism. At the heart of the success of these sectors is the most valuable resource – human capital. The adaptation of human resources to the specific requirements and challenges of the blue economy is essential for achieving sustainable growth and innovation. This material will examine the key role of human resources in the development of the blue economy and will analyse how they can be effectively adapted to the new realities related to technologies, skills and policies.

The wide range of problem areas requires a reassessment of the situation and to consider it in the context of the preparation and adaptation of human resources for the development of the blue economy in the aspect of its modern technical, technological and social significance, as well as from the perspective of the green and digital transformations of the sector. That is, the human resource responsible for the various areas of management and protection of the marine ecosystem and its functioning as a sustainable blue zone. These responsibilities are predominantly outlined in the environmental and economic spheres, related to some of the challenges: pollution and eutrophication, monitoring of marine and coastal areas by expanding the network of research and monitoring control /which in some countries still remains incomplete/, research of risks and risk areas, for which risk assessment and analysis are necessary to take preventive measures, the participation of the civil sector in the management of HR, the low level of knowledge about the marine environment, insufficient skills for using innovative methods in the management of the marine ecosystem, digitalization, green transformations and active inclusion of scientific research in the systems for the protection of the marine ecosystem and improving the interaction between education, science, business and the civil sector.

All countries in the Black Sea region are addressees of the challenges, but respond in different ways, although subordinating their policies to the principles of the Integrated Maritime Policy and the EU's actions regarding the Black Sea.

The data cited in the publication were collected from the Black Sea Institute’s own research, as well as from the discussions at the annual round table “*The Sea – Border or Door*” for several years [1].

A study by the Black Sea Institute Association shows that the most serious challenges facing the Black Sea region are political challenges (Figure 1)[1].

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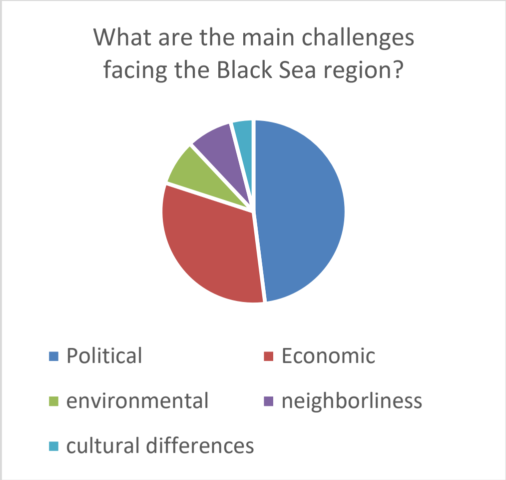

Figure 1 The main challenges facing the Black Sea region [1]

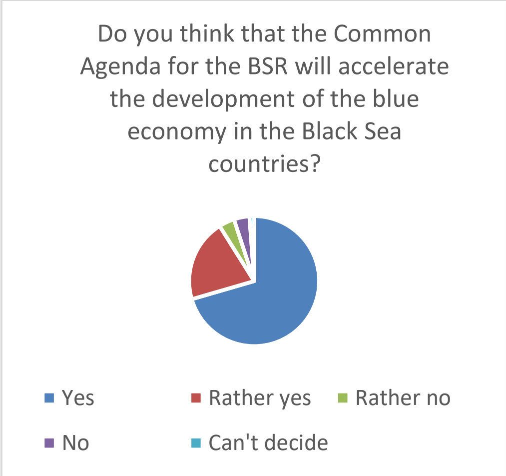

Figure 2 The influence of Common Agenda for the Black Sea region [1]

Obviously, the residents of the region define the situation in the Black Sea region as risky, and this means that the situation should be taken into account, i.e. to seek solutions for the development of the blue economy in the conditions of crisis.

The countries of the Black Sea region have always been characterized by serious differences in terms of their economic development, confirmed by the second position of the economic challenges. Even more so in the conditions of military operations that are being conducted on the shores of the Black Sea. It is interesting, that environmental challenges are almost equal to the others, because until recently they were dominant.

The need for a Common Agenda for the development of the Black Sea region is recognized, which clearly shows that the process that began with the Black Sea Synergy has not yet yielded the necessary results. The expectations that such a Common Agenda will be created and developed by the EU indicate that the countries do not take into account the existence of their own capacity to develop national strategic guidelines and visions for the development of their own Black Sea territories, taking into account the principles of the Integrated Maritime Policy and the blue economy (Figure 2).

The situation with the pandemic, and subsequently with military operations, showed the need for sustainable practices in the management of marine resources. The ongoing economic turmoil shows that coastal communities need to diversify their sources of income to withstand economic and social shocks. Cumulatively, several elements can be outlined that are relevant and that should be taken into account by all institutions and organizations in each of the Black Sea countries involved in the management of the blue economy (Figure 3) [2]:

Figure 3 The challenges to the health of the oceans and seas [2]

All the elements mentioned are related to the human resource involved in the blue economy. The problems before the crisis manifestations increase seriously during the crises, but unfortunately there are no studies that determine the degree of influence. As can be seen from the priorities of the blue economy, it refers to the sustainable management and use of marine resources, which can play an important role in economic recovery and sustainable development in general. With the understanding that the development of the blue economy is one of the economic potentials in its reasonable and adequate use, since it refers to the use of entirely natural resources [2].

To overcome the challenges facing the blue economy, we will pay attention and outline the necessary directions for the preparation and adaptation of human resources, as the most strategic resource for participation in achieving blue growth, emerging as an important result of the use of the planet's blue wealth. Cooperation in the management and development of the blue economy, and the participation of the civil sector in the management of maritime regions, knowledge and skills,

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are among the most important groups of factors that determine the participation of human resources in the blue economy, taking into account the trends of globalization, the search for synergy and economic and social transformations.

Bulgaria and Romania – as well as some of their key regional and local stakeholders endorsed the Charter of the EU Mission 'Restore our Ocean and Waters by 2030', committing to accelerate the restoration of the Danube River and Black Sea region [3]. High-level representatives from both countries, including the Bulgarian Minister of Environment and Water, officially endorsed the Charter at the 'From the Danube Source to Black Sea – Healthy Waters and Healthy Life' event in Burgas, Bulgaria. Joined by other key regional stakeholders including the Burgas Free University, Constanta Municipality and local schools, they pledged national actions to restore the Danube and Black Sea [4].

2. COOPERATION IN THE BLUE ECONOMY

The areas for cooperation in the blue economy are quite diverse. The expectations for cooperation, according to studies by the Black Sea Institute Association, distribute this diversity as follows: tourism 97%; trade 84.2%; joint production 66.7%; information technology 54.%%; shipbuilding/ship repair 60.6%, fishing 54.5%; aquaculture 63.4%, agriculture 21.2%. In the hands of human resources are many opportunities that depend on the initiative, knowledge and competence of potential participants. Purely maritime areas of interest collect a high overall share of preferences, although they rank lower than tourism and trade /it should be understood that if we talk about tourism here, we mean maritime tourism/. Cooperation between institutes and organizations can optimize the use of marine resources, the sharing creates interaction and synergy. The sustainable development of the blue economy requires the involvement of local communities to ensure that their needs and interests are taken into account, as the risk of economic losses for fishing communities affects not only trade, but also the labor market related to the blue economy, the creation of new jobs, the qualification of participants and the acquisition of knowledge and skills specific to the blue professions, as well as the quality of life along the coast. A number of European funds and programs /Maritime Affairs and Fisheries, Horizon Europe/, as well as the Joint Operational Program "Black Sea Basin" are also working towards cooperation. There are already hundreds of projects, reflecting the idea of Black sea cooperation, which have been financed under this program, there are also many cross-border partnerships created by the consortia that developed the projects, innovative technologies have been created, ideas for the development of the blue economy have been brought forward. However, in order to achieve sustainable results, it is necessary to establish post-project requirements through which partnerships can be continued, i.e. projects should not be considered as independent entities, but to seek the continuation and realization of jobs and employment. Only in this way the sustainability of the results, especially when it comes to infrastructure projects and those that would bring high added value, will become a real result and multiply blue growth. A cursory analysis of the projects financed under the OP "Black Sea Basin" shows a significant share of projects to combat plastic waste, but the real result of them is not yet available. The improvement of environmental indicators on the Black Sea coast is more likely due to reduced economic activity than to effective activity under the program.

3. KNOWLEDGE AND SKILLS FOR IMPLEMENTATION IN MARITIME PROFESSIONS

To fulfill the key role of human resources in the blue economy, technical skills (marine engineers, renewable energy specialists, marine biologists, aquaculture specialists), management and entrepreneurial skills for maritime business, skills for working with new technologies (digitalization, automation in the maritime sector), combined with environmental and conservation knowledge are needed. Innovation and competitiveness contribute to the sustainable management of marine resources, which is why the exchange of experience and innovations between different regions can accelerate the transition to a dynamic blue economy. Different levels of education offer different opportunities for increasing knowledge about the sea and create specialists in the blue professions, but a lot of effort is needed to motivate human resources to focus on them. Ignorance of blue professions is one of the problems and obstacles for young generations to orient themselves towards them. Professional guidance and career development come to the rescue. The Black Sea Institute created promotional cards of the blue professions it works with adolescents in the process of career guidance (Figure 4).

Figure 4 The promotional cards of Black Sea Institute.

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In Romania, “The persons who want to sail the seas and oceans of the world, must consider that the compulsory education include graduating a maritime higher institution in order to access a career in navigation. They can choose to study in a university either to become officers for the **Romanian Naval Forces**, or **maritime officers and engineers** for the **merchant marine navy**. There are many specializations that can offer training for all type of activities related to maritime sector and here are some examples: Navigation, Naval Architecture and Marine Engineering, Naval Systems and Technologies, Mechanical, Industrial and Maritime Engineering, Shipping and Port Management, Telecommunication Systems, Environmental Engineering, Naval Transport, Business and Engineering in Transports etc.”(Figure 5)[5].

Figure 5 The promotional materials of Constanta Maritime University [6]

The blue economy at the European level creates a constantly increasing number of jobs, generates an increasing share of revenues. A WB report on Bulgaria provides data on the good development of the blue sector “Several marine-based sectors, including coastal and maritime tourism, fishery and aquaculture, shipping, ports, ship building and repair, and oil and gas exploitation, roughly €995 million in gross value added (GVA) in 2018, which is roughly 2 percent of the national GVA of all economic sectors and accounts for 3.4 percent of all jobs ”[7]. However, there is an increasingly fragmented management of coastal and marine natural resources, due to a lack of vision, national strategy and consistency in sectoral policies and market development at the regional and national levels. It is essential to adapt human resources to the new technological realities and challenges of the blue economy. Which requires a lot of effort to master the digital and green innovations entering all spheres. Human resource adaptation is a two-way process – on the one hand, people adapt to new elements, and on the other hand, people create new technologies and innovations. That is why human resource adaptation to the blue economy means: developing specialized programs in universities and vocational schools; creating conditions for the development of blue innovations; improving the qualification and retraining of the existing workforce; developing digital and green skills; focusing on digital skills and working with data. developing soft skills (communication, teamwork, flexibility); increasing environmental and resource efficiency. The most important thing in adaptation is developing analytics, through which the necessary changes and the ways in which they are introduced are assessed, so that they correspond to the databases of processes accumulated so far, so that the transition is consistent and successful and does not have an unexpectedly destructive effect on the marine ecosystem. Mechanical adaptation to any technological transformations is dangerous for the health of the ecosystem. “ The wise man adapts himself to the world, the foolish man adapts the world to himself..”(Bernard Shaw).

4. CITIZEN PARTICIPATION IN THE MANAGEMENT OF MARINE RESOURCES

The Black Sea Institute's own research indicates that citizens, through their civil structures, hardly find a place in the management of the Black Sea territories and the marine ecosystem, citizens know little about the use of marine resources. Citizens give a low assessment of the management of marine territories, but they turn out to be only "consumers" of the challenges and with almost minimal opportunities for influence (Figure 6, Figure 7, Figure 8). Rather, their participation is to oppose some unfavourable decisions of various types of authorities regarding the marine and coastal environment /e.g. protection of dunes, protected areas, counteraction to overdevelopment, etc.

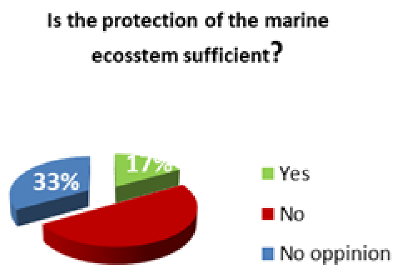

Figure 6 The protection of the marine ecosystem assessment

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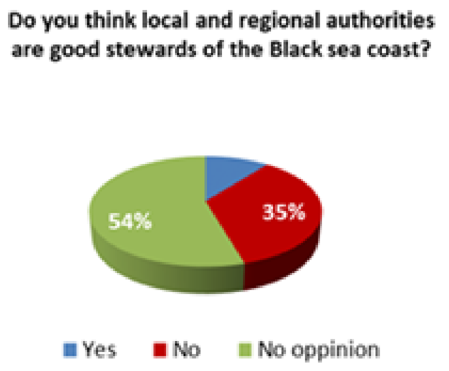

Figure 7 The assessment of regional authorities.

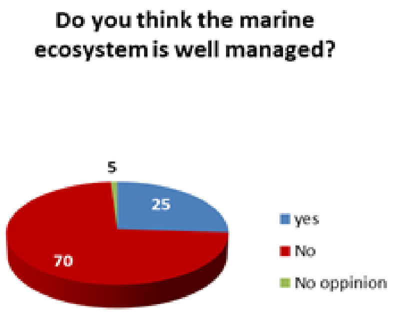

Figure 8 The assessment of marine ecosystem's management.

Citizens do not know enough about the marine ecosystem and its features, which is why they are not well acquainted with the resources of the sea. The most acceptable use of the sea is its tourist potential, and in a simpler form - beach tourism, attractions, etc. But the resources of the sea remain hidden from view, and this is an important reason to look for ways to increase knowledge about the sea (Figure 9, Figure 10).

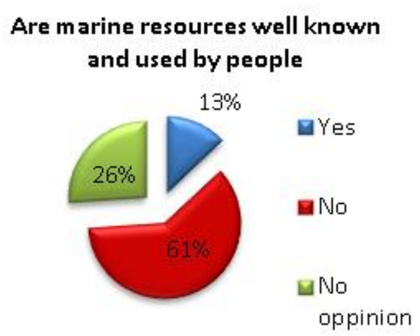

Figure 9 The assessment of marine resources well known and used by people.

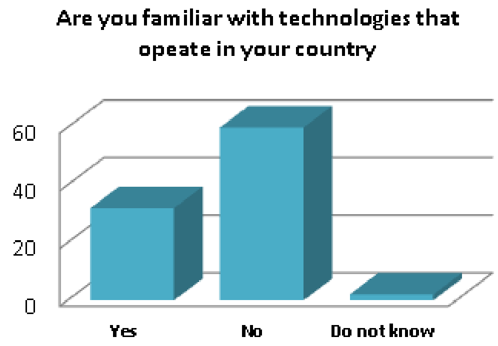

Figure 10 The assessment of knowledge of the technologies that operate in your country.

The implementation of digital technologies in the Romanian's seaports would be extremely beneficial for:

- coordinating port operations,
- avoiding unexpected events,
- safer port operations,
- increased shipping security,
- avoiding delays in the transport chain,
- understanding potential threats and realities on port facilities,
- and their adoption in Romanian seaports prepares the transition to the smart port [8].

Although the majority of citizens have insufficient knowledge about the sea, they assess the mix of problems of the sea as serious, because the result of the manifestation of the problems actually reaches them, namely - high level of eutrophication, deteriorated water quality, change to degradation of biodiversity, strong dependence of a healthy and balanced environment on marine activities and industries such as fishing, aquaculture and tourism, offshore activities. This is the reason why they treat with extreme distrust various types of innovations such as oil and gas extraction, the placement of energy production facilities on the coast or on the shelf, etc.(Figure11, Figure 12).

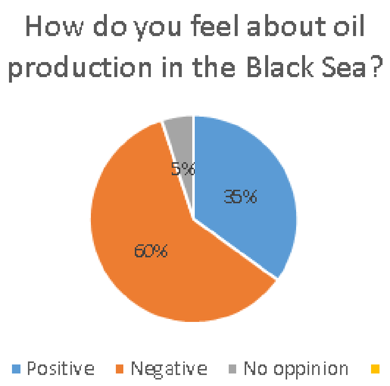

Figure 11 The assessment of oil production in the Black Sea.

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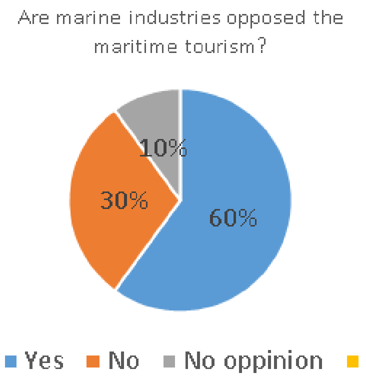

Figure 12 The assessment of marine industries opposed the marine tourism.

Each of the challenges needs serious analysis in order to be specifically addressed and overcome. The problem is that none of them acts independently, they are interconnected, which is why a synergistic direction must be sought to overcome them, which is difficult due to the asynchronous actions of the different types of authorities and institutions.

The challenges cited above have been repeatedly noted in a number of EU documents concerning the Black Sea and the Black Sea region, but the development of activities over time is quite slow [9], [10]. Their implementation almost exclusively on a project basis, provided by various European programs, is extremely insufficient, scattered in terms of focus and limited within the goals of each consortium implementing the project, regardless of the adopted general principles of each of the programs. Projects are developed without commitment and overlapping of results, partnerships are unsustainable, which also predetermines lower than expected results. The starting point for improving the situation is to increase the participation of the civil sector in the management of the Black Sea zones in each of the littoral countries, creating a strategic agenda for each of them, subject to the general principles for the development of the blue economy and blue growth, with the obligatory search for synergy in actions.

5. POLICIES AND SOLUTIONS

Building a vision for the development of the Black Sea region, accompanied by a national integrated agenda, ensuring synergy between education, science, business initiatives, state support, public-private partnership, subordinate to the protection of the marine ecosystem and the reasonable exploitation of marine resources.

Adaptation of human resources to the challenges of the blue economy;

Education and training: Development of specialized programs in universities and vocational schools; Upskilling and reskilling of the existing workforce; Promoting lifelong learning;

Skills development: Focus on digital skills and working with data; Development of soft skills (communication, teamwork, adaptability); Increasing environmental and resource efficiency.

Supporting policies: State policies to stimulate employment and development in the blue sectors; Cooperation between business, education and the state; Promotion of entrepreneurship in the blue economy; Synchronization in the activities of different types of authorities and institutions.

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PROSPECTS FOR THE USE OF R290 REFRIGERANT IN MARINE REFRIGERATION EQUIPMENT

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Abstract : The need to replace traditional refrigerants in marine refrigeration equipment with low-GWP alternatives is growing due to international climate regulations. This paper discusses the current status and potential of R290 (propane) as a long-term substitute in marine air conditioning systems. Compared to other refrigerants, R290 offers higher energy efficiency, low environmental impact, and compatibility with existing system designs. Challenges related to flammability are addressed through compliance with safety standards and technical solutions approved by major classification societies. Calculations of performance parameters under different climatic conditions support the feasibility of switching to R290 as a sustainable alternative.
Key words : air conditioning system, climate impact, electricity consumption, energy efficiency, environmental friendliness, marine refrigeration, refrigerant.

1. INTRODUCTION

Global legislation such as the Paris Agreement, the Kigali Amendment, and the EU F-Gas Regulation aims to reduce hydrofluorocarbon (HFC) emissions, including those used in marine applications. The gradual phase-out of HFCs encourages the adoption of environmentally friendly alternatives. As one of the largest transport sectors, shipping must proactively implement green technologies.

Classification societies such as Lloyd's Register, DNV GL, and Bureau Veritas now promote refrigerants with a global warming potential (GWP) up to 2000, thereby excluding many traditional working fluids like R404A. Due to the need to reduce the environmental footprint of ship systems, there is increasing interest in natural refrigerants with zero or low GWP, such as CO2 (R744), ammonia (R717), and propane (R290) [2]. However, each of these options has specific limitations: R744 operates at high pressures, and R717 and R290 are flammable.

According to international standards (ISO 817, ASHRAE 34) and conventions (SOLAS, MARPOL, IGF, and IGC Codes), the use of flammable refrigerants onboard is not prohibited. Leading classification societies now allow their use, provided safety measures are followed. More regulators now recognize the safe use of R290 if refrigeration systems are properly designed and maintained.

2. R290 PROSPECTS AS A MARINE REFRIGERANT

R290 is currently regarded as one of the few refrigerants that meet the critical requirements of environmental friendliness, energy efficiency, and availability [2, 3]. With a GWP of around 5, it has minimal climate impact. It also has high energy efficiency: the coefficient of performance (COP) is 5…10% higher than that of R404A, R134a, and HFOs such as R1234yf, depending on the equipment. R290 can be integrated into traditional system designs without major modifications, unlike CO_2 or ammonia systems. It is also much cheaper than HFOs. Recently, R290 has been approved by Lloyd's Register, which is a significant milestone.

R290 is already in use in marine applications. For example, Thermo King and GIZ are working on a marine reefer container project called Greener Reefers, with new safety standards expected by 2026. Heinen & Hopman has proposed technical solutions for the safe use of R290 on board. Cooling Post and Johnson Controls are also developing propane- and propylene-based systems. Hydrocarbon refrigerants are already used in reliquefication systems on gas carriers and may be adapted for use in general marine refrigeration systems.

However, it is still debatable whether flammable refrigerants like R290 should be widely used before strict GWP limits are enforced. This paper analyses the advantages of R290 as a replacement for R404A and

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other alternatives in terms of energy and fuel savings in marine air conditioning systems.

3. EFFICIENCY ANALYSIS OF ALTERNATIVE REFRIGERANTS IN MARINE AIR CONDITIONING

A typical refrigeration unit for marine air conditioning systems, such as the "YORK Marine" plant manufactured by Hi Air Korea Co., Ltd., was selected for the comparative analysis of various refrigerants. The schematic of the refrigerant and cooling water circuit is shown in Figure 1. The general specifications are presented in Table 1.

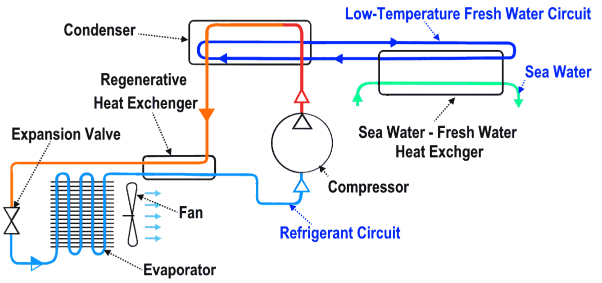

Figure 1 Schematic diagram of refrigerant and cooling water circuit in a marine air conditioning unit

Table 1. General specifications for the marine air-conditioning system

Parameter	Characteristics
Refrigerant	R404A
Compressor type	Sabroe SMC 106 S
Compressor ,Vh	339 m3/h at 1500 rpm
Condensing temperature, t_c	+42 °C
Evaporating temperature, t_{ev}	+7 °C

** data was accepted according to the marine air-conditioning system manual*

It should be noted that due to their design, air conditioning systems on merchant ships can be installed in separate ventilated compartments, meeting the requirements of classification societies (e.g., Lloyd's Register) for systems using flammable refrigerants. However, this is not feasible for the provision refrigeration systems without an intermediate brine circuit.

To assess the feasibility of using low-GWP alternatives, the energy performance of the marine air conditioning unit operating on selected refrigerants was analysed. Table 2 summarizes their characteristics. R404A was used as a baseline, R407F as a widely used retrofit option, and R134a and R32 as common in air conditioning but not low-GWP. R290 and R1234yf were considered as promising long-term options with very low GWP.

Table 2. Main characteristics of selected alternative refrigerants

	R 404A	**R 290**	**R 407F**	**R 1234 yf**	**R32**	**R 134a**
GWP, kg CO_2/kg of refrigerant	3940	5	1670	<1	677	1300
The normal boiling point, °C	-46.6...-45.8	-42.1	-46.1…-39.7	-29.45	-51.7	-26.07
Refrigerant safety class	A1	A3	A1	A2L	A2L	A1
Approved by classification societies	LR, BV, DNV	LR	LR, BV, DNV	DNV, BV	DNV, BV	LR, BV, DNV

Compressor power was estimated using RefProp 10.0 thermo-physical properties [5]. Volumetric and isentropic efficiencies of the reciprocating compressor were considered, with a shaft speed of 1410 rpm. The results of electrical COP and cooling capacity at varying condensing temperatures are presented in Figure 2 and Figure 3.

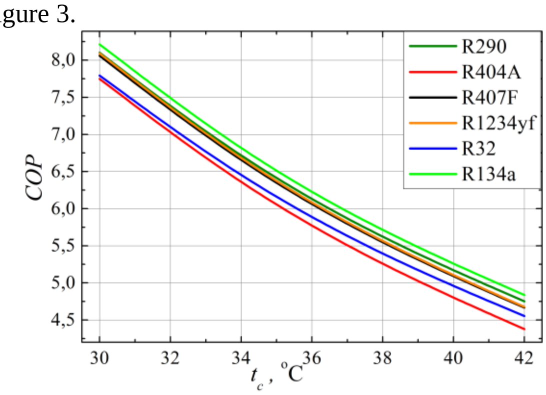

Figure 2 Electrical COP vs. condensing temperature for marine air conditioning system

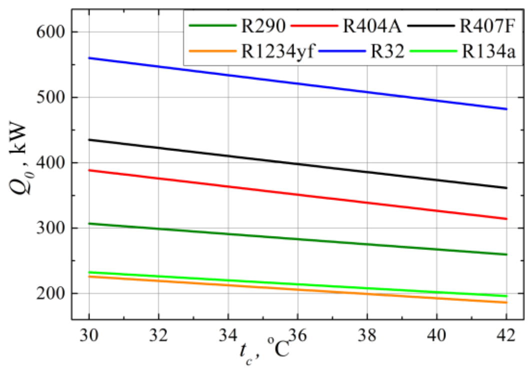

Figure 3 Cooling capacity vs. condensing temperature for marine air conditioning system (SMC 106 S compressor)

As shown in Figure 2, R134a provides the highest COP regardless of condensing temperature. However, it

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is not commonly used due to the industry trend of using a single refrigerant for both air conditioning and provision systems. R407F offers a higher COP than R404A and is a common short-term substitute. R1234yf and R290 show similar performance, with R290 slightly outperforming at higher condensing temperatures.

Figure 3 shows that the use of R1234yf, R290 and R134a in a system with an SMC 106 S compressor (V_h = 339 m^3/h) leads to a significant reduction in cooling capacity Q_0. Therefore, if the refrigeration machine is converted to one of these refrigerants, the compressor will need to be replaced. Unlike R1234yf, R290 and R134a , R407F provides an increase in cooling capacity, which is why it is currently used to directly replace R404A. A new compressor for each of the refrigerants under consideration was selected according to [7]. Table 3 lists the updated compressor parameters and resulting cooling capacities.

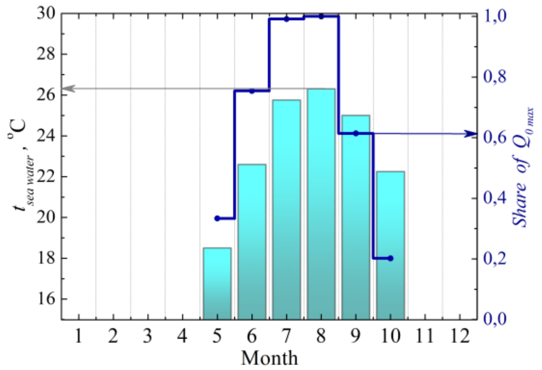
Table 3. Compressor parameters and cooling capacities of refrigeration machine

	R404A	**R290**	**R407F**	**R1234yf**	**R32**	**R134a**
Compressor name	SMC 106 S	SMC 106 L	SMC 106 S	SMC 108 L	SMC 104 S	SMC 108 L
Compressor V_h at 1500 rpm, m^3/h	339	424	339	566	226	566
Q_0 at t_c=42 °C	314.2	324.7	361.4	310.8	321.3	327.3

Next, we analysed the energy consumption of air conditioning systems using the refrigerants under consideration when operating in different climatic conditions:

- in a tropical climate (port Kingston, Jamaica, as an example);
- in a region with a temperate climate (port Piraeus, as an example).

The load (required cooling capacity Q_0) on the system was estimated for each month based on the average monthly outdoor air temperature (it was assumed that for the hottest month the load was 100 % and equal to Q_{0max} = 314.2 kW as for a system using R404A at t_c = 42 °C) - Figure 3. The temperature of the on board water is taken according to [8] - Figure 4. These data were used in the further analysis to determine the total annual electricity consumption by the air conditioning system's refrigeration machine.



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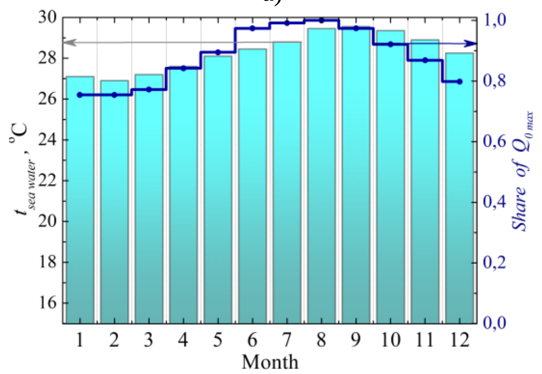


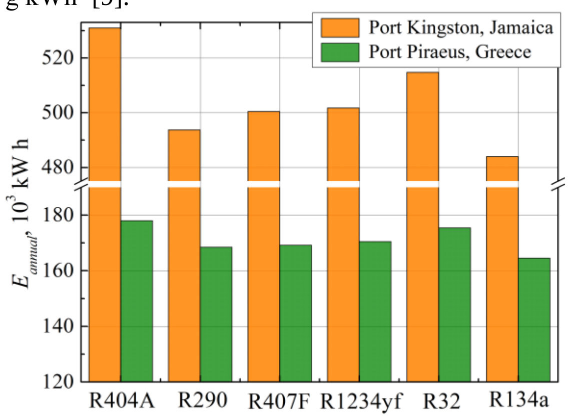
b)

Figure 4 The average monthly temperature of the seawater [8] and the share of the required cooling capacity of the air conditioning system from the maximum for the climatic conditions of two ports: a) Piraeus, Greece and b) Kingston, Jamaica.

The annual electricity consumption of the refrigeration compressor (including the energy consumption of the exhaust fan for flammable refrigerants) is shown in Figure 4.a.

Figure 4.b shows the annual fuel savings when the air conditioning refrigeration machine is converted to an alternative refrigerant. It was assumed that electricity is generated by a diesel generator (MDO as a fuel).

The base value of specific fuel consumption is 185 $g \cdot kWh^{-1}$[9].



a)

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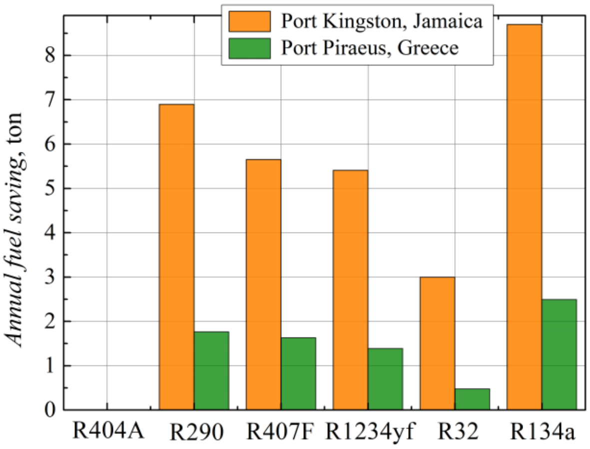

b)

Figure 5 Annual electricity consumption (a) and fuel savings (b) when operating a ship's air conditioning refrigeration machine with different refrigerants in regions with different climates

As can be seen from Figure 5, the lowest energy consumption by a refrigeration machine (8.9 % less than R404A) and the highest annual savings in ship fuel (8.9 tonnes) are achieved by using R134a refrigerant (based on the example of the Port of Kingston). The next most efficient refrigerant is R290 (7.0 % reduction in energy consumption and 6.9 tonnes of fuel savings). R32 has the least (but positive) effect of all refrigerants. R407F refrigerant, as a short-term alternative to R404A, provides a 5.8% reduction in energy consumption and 5.7 tonnes of fuel savings per year (based on the example of Kingston port). An interesting result was obtained: all alternative refrigerants provide greater energy savings for the refrigeration system compared to R404A when operating at high condensation temperatures (based on the example of the Port of Kingston).[10]

If we analyse the above results and calculation data, we can see that in the short term, R407F is an alternative refrigerant. It can be changed as part of a retrofit procedure (without replacing major components), and it provides fairly high COP values (Figure 2) and fuel economy (Figure 5). However, it cannot be considered in the long term due to its high GWP. R134a cannot be considered as a promising refrigerant in the short term due to the need to replace the compressor, although it has a lower GWP than R407F. R32 loses out in many respects: it has a low COP, is flammable and is not one of the refrigerants with a very low GWP.

R290 looks promising as a long-term replacement for R404A in the ship air conditioner under consideration. Compared to R1234yf, it provides greater fuel economy and is much cheaper.

The main disadvantage, flammability, is common to both of these refrigerants.

4. CONCLUSIONS

Despite the challenges associated with flammability, R290 is the most promising refrigerant for marine refrigeration. Its advantages in terms of energy efficiency, environmental friendliness, compatibility with existing systems and low cost make it inevitable that it will be adopted in the future. With proper compliance with technical standards and staff training, its introduction could become a benchmark for sustainable development in the shipping industry.

Safe implementation relies on proper engineering design and adherence to standards such as Lloyd's Register, EN 378, ISO 20854:2019, IEC 60079, etc. Currently, Lloyd's Register permits the use of R290 under conditions such as dedicated compartments, mechanical ventilation, and gas detection systems.

Transitioning to R407F is recommended as an interim solution, especially for existing ships where full modernization may not be practical.

A long-term strategy for marine refrigeration should focus on natural refrigerants, particularly R290.

5. ACKNOWLEDGMENTS

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A CASE OF STUDY ON YOUTH INTEREST IN ENVIRONMENTAL ENIGINEER PROFESSION WHICH IS IN THE HEART OF RENEWABLES

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Abstract: Environmental engineering programs are extremely important having in view the projected job growth and the increase in global demand for solutions to face environmental challenges. Universities all over the world respond to this need by providing specialized environmental engineering degrees. It is also the case of Constanta Maritime University which is coming to reply to this request by developing the Engineering and Environmental Protection in Industry program. This is a result of the fact that there is a strong need that each of us should be informed about the environment situation, through out environmental awareness. This concept leads to public health and well being of the environment. On the other hand, we assist to population growth- process direct linked to higher energy demand. In this context, the use of renewable energy sources is of great importance since their impact on the environment is considerable less then traditional ones. This paper exposes a planned and carried out activity by Constanta Maritime University and its 4 partners- high schools with energy profile in the country. The activity called *"I choose to become a specialist in renewables"* is, in fact, a competition aiming to rank essays reflecting the vision of high school students regarding this profession, to analyze a survey conducted to assess the level of environment awareness of the young participants and to facilitate a discussion between the respondents and teachers specialized in the field. The findings are encouraging: the scientific board of the competition found motivating ideas in the presented essays and the survey revealed that the students coming from high schools with such a profile shows maturity and understanding of current environmental issues.
Key words: youth, environmental engineering, renewables, awareness.

1. INTRODUCTION

The evolution of our society lowered the quality of our life because of pollution and, implicitly, climate change. This is why, lately, a profession gained more and more importance on the labour market: environmental engineer. This important career is based on bachelor's degree in environmental engineering. Gaining the required skills during their education, environmental engineers are able to balance the development of our modern society and the wise use of natural resources. They target the desiderate of preserving Earth habitable and thriving for the next generations.

Engineering and Environmental Protection in Industry is a program of study, developed in Constanta Maritime University, aiming the specialization in applied technologies, which, through out the integration of technical and scientific knowledge, deals with the specific problems met in the fields of energy and natural environment conservation, active production, waste control. The specifics of the specialization involve deepening knowledge on Environmental Engineering in Industry, i.e. on wastewater management, combating air pollution, waste control, recycling and disposal, radiation protection, industrial hygiene, studies on the environmental impact of proposed construction projects, risk management with environmental applicability.

In order to ensure the penetration of the importance of this academic programme among young people, Constanta Maritime University makes use of the following actions:

– taking advantage of online communication and promotion opportunities by managing the university's social networks,
– promoting in the media academic, research or scientific events taking place in the faculties and the university, as well as the professional achievements of the members of the academic community,
– implementing an effective marketing strategy to increase the visibility of the University and to highlight the distinct advantages of the academic programs, by using online channels, social networks and promotional events,

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– promoting the educational offer of the faculties and admission to the various study programs, as well as informing potential candidates through the managed communication channels,
– participating in educational offer fairs and national and international scientific exhibitions,
– carrying out marketing activities within high schools and co-opting students in scientific activities, under the guidance of university teaching staff.

An important activity aiming the attraction of future professionals in the mentioned sector is the organization by Constanta Maritime University CMU), in cooperation with high schools with energy profile in the country, within a yearly scientific competition called *"I choose to become a specialist in renewables".*

This type of activity will be a good opportunity to disseminate and promote the results of teachers and students, learn about the latest achievements in the field of the topic addressed, maintain contact between specialists, stimulate students' creativity, and identify opportunities for valuable collaborations and partnerships with university education. The competition is addressed to students and teachers in activating within technological education, with the collaboration of teachers in university education. The objectives of this activity might be summarized as:
– familiarization of high schools students with the profession of environmental engineer and rise the awareness regarding the importance and use of green energy,
– developing students' interest in documentation, research, innovation and comparative analysis,
– stimulating creativity in the development and presentation of papers, reports, projects,
– presentation/ dissemination of examples of good practices, material and procedural resources, developed and applied interdisciplinary in order to support skills gain and training- according to professional training standards,
– presentation of essential data, relevant and useful information, with the aim of creating a documentation support, to support lifelong learning through improvement, orientation towards a possible future career, professional retraining or updating/diversifying knowledge and motivation for lifelong education.

The competition consists in the elaboration by the participating students, under the advice of a coordinator professor, of an essay on the announced topic. The paper will present the students' vision regarding renewable energies and the justification for their choice of a profession/specialization in this field.

Previous to the competition, high school students are provided with a scientific material on renewables, elaborated by specialised CMU staff.

After the presentation of the essays, the competitors are interviewed, thorough out a questionnaire developed by CMU staff, in order to be assessed the level of renewable energy among the young participants.

Part of the scientific board, including high school professors and CMU academic staff is evaluating and ranks the submitted essays. Resulted important ideas will be given in the next section of the paper. The other part of the scientific board is assessing the results of the survey. At the end of the competition called *"I choose to become a specialist in renewables",* will be a Discussion Session between teachers and student participating.

The number of high schools students involved was 25. Their ages vary between 17- 18 years.

2. MATERIALS AND METHODS

The development of our modern society is based on energy consumption. In present times it is vital to pay a careful attention on new energy sources, based on environmental friendly technologies, to the detriment of traditional ones: thermal, electrical or mechanical energies; renewable energy sources are those type of sources able to exist any day within the cycle of nature as a way to ensure environment protection and a healthy planet for *future generations* [1]. Technologies based on renewable energy sources are found in sectors such as electric power, heating and cooling or transport and include solar or wind power, biofuels, waves, tides, geothermal energies and so on [2].

Many studies reveal that students have a positive attitude regarding the environment [3]. The board in charge with the evaluation of the essays found interesting ideas written down by the competitors':

"I wish to become a specialist able to understand, develop and implement, both as an individual and in a team, the latest knowledge regarding the conversion of renewable energy sources, based on the accumulation of theoretical and applied knowledge under optimal technical and economic conditions".

"I would like to join the mission of identifying renewable energy resources, converting them as efficiently as possible into other types of energy, and managing and optimizing energy consumption, through knowledge of the phenomena that govern the respective field and related fields, in order to support current and future civilization".

"I am highly interested in an educational program which trains specialists in the field of renewable energies, since the job market being constantly growing and the need for well-trained people will be greater in the following years".

"I would like to study interesting topics related to energy storage, passive houses, energy efficiency, environmental audit, nanomaterials for green energy, eco nanotechnologies, simulation and modeling for renewable energy sources".

"In the future, I wish to be able to design, plan and manage construction-installation projects based entirely on renewable energy sources or/and hybrid installations (simultaneously having both classic and renewable energy sources)".

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Besides the investigation of the interest of targeted students regarding a future career in renewable energy sources, this study intends to assess the knowledge and the attitude of participants regarding renewables and endangerment of the environment. The survey presented in the following falls into many researches pointing out the importance of social responsibility in the context of seeing the human's inadequate behavior in confront with the nature [4].

3. THE SURVEY- RESULTS AND DISCUSSION

The survey is a result of investigation existing literature sources [5], [6], [7]. This survey consist in 13 statements, for which a scale between 1 and 5 rates the level of acceptance of each statement. Thus 1- means *strongly agree*, 2- means *agree*, 3- means *unsure*, 4- means mildly *disagree* and 5- means *disagree*. The 13 statements included in the survey are given below.

1. Do you agree that any individual should act environmentally conscious even if others act in an opposite way?
2. Do you agree that lockdown had a temporary positive effect on the environment, but the post- lockdown period brought back the environmental issues?
3. Do you agree with the fact that recycling can diminish the threat of global warming?
4. Do you agree that using fossil fuels in order to generate electricity led to the increase in CO_2 in the atmosphere?
5. Do you agree with the actions taken by your local authorities in respect with environment protection?
6. Do you agree that Romanian young people is more familiarized with environmental issues and renewables use than the rest of the population?
7. Do you agree that education entities, media, public authorities, stakeholders and ONGs should be more involved in create environmental awareness among young people by underlying the importance of using renewables?
8. Do you agree with an intense use of renewables in order to respond the increased energy demand?
9. Do you agree with the level of public investments in the use of renewables?
10. Do you agree that traditional forms of energy are damaging the environment?
11. Do you agree with the fact that in Romania traditional energy resources are more spread than the clean ones?
12. Do you agree that Romania has a good position and climate features in order to intensify renewable usage?
13. Do you agree to invest in solar panels to be placed on the roof of your home?

All the participants were strongly agree with the first statement, as well as in the case of the statement 2, 3 and 4. This situation reflects that the participants show a pro-environmental attitude and intention, due the fact that their educational level is linked to environmental values.

Figure 1 reflects the answers recorded for statement 5. Results that the participants perceive that local authorities are not doing enough in this sense seing insufficient action or engagement.

Figure 2 reflects the answers recorded for statement 6. During the discussion session, students said that educated young people, living in big towns might be better informed. They stated that it is important to take into consideration social aspects such as education, gender, age, socio-economic status.

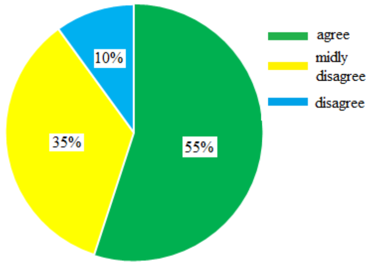

Figure 1 Replies to statement 5

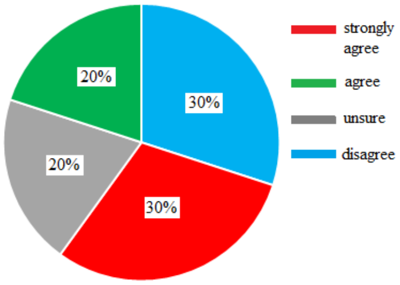

Figure 2 Replies to statement 6

Statement 7 gathered unity in answers, all of them being "strongly agree". This situation is pointing out once again how important is that all the mentioned actors should strongly collaborate to preserve a sustainable healthy environment. The same situation resulted in the case of statement 8. This reflects the fact that young people show long-term perspective on climate change and creative thinking. Answers related to statement 9 are provided in Figure 3. During discussions, students said that Romania do not respect European Commission recommendations regarding the new renewable energy target, being needed the acceleration of renewable energy projects.

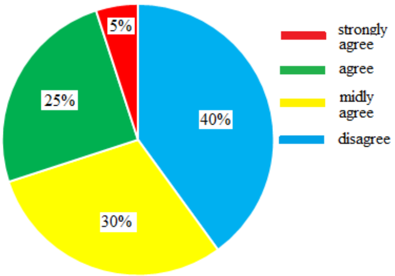

Figure 3 Replies to statement 9

The position of competitors found in the case of statement 10 is depicted in Figure 4. Students said that

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traditional energy sources are responsible for the gradually raising the overall temperature of the globe.

Another unanimity ("strongly agree") was seen in the case of statement 11. Students seemed to be well informed when they said that traditional energy sources are the most consumed energy sources in the world, not only in Romania. They wish to contribute, in the future, as professionals in finding a long term solution for the human beings to manage their existence with green energy resources.

Same unanimity ("strongly agree") was also found in the case of statement 12. Students were informed that Romania "is blessed" with a good geographic position due to its mountains, hills, plains, and seashore and possesses climate features that support important potential for renewable energy development such as solar, wind, hydropower or biomass.

Figure 5 reveals the situation regarding statement 13. The vast majority ("strongly agree") was able to support their choice with pros such as: cost savings, enhanced property value, environmental impact, energy independence, non-maintenance. [8]

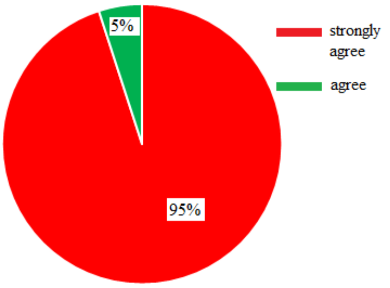

Figure 4 Replies to statement 10

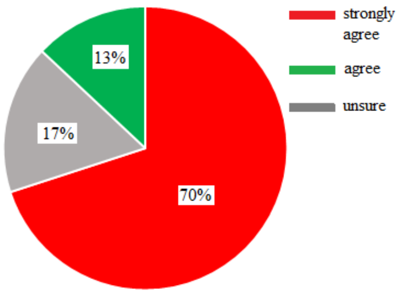

Figure 5 Replies to statement 13

The main reasons for which the rest did not tick "strongly agree" were high costs of investments, unpredictability regarding cofounding, uncertainty in respect with the location of their future home.

4. CONCLUSIONS

The main findings of this paper are summerized as:

– the participants are interested in preserving the environment seeming to be motivated to study environmental engineering;

– this type of high school students are aware of environmental issues and ready to adopt the right personal behaviour in their daily life;

– these students are enthusiastic to cooperate with their teachers and to exchange ideas in an academic environment;

– they seem to have a realistic perspective on the role of education, authorities, media in the rise of public awareness and establishment of future strategies;

– participants are a category of young people showing a positive attitude in confront with renewables.

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DESIGN AND VALIDATION OF A LOW-COST SONAR PROTOTYPE FOR SYNTHETIC DATASET GENERATION IN UNDERWATER MINE DETECTION

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Abstract **:** Detection of underwater mines is very important for military, maritime security, and environment safety applications. However, the development of machine learning models is limited heavily because of the lack of quality labeled sonar datasets, especially in military contexts as the data there is highly confidential and expensive. The problem with current synthetic datasets is that they fail to properly replicate how complex operational underwater environments are which leads to major performance gaps when deployed in the real world. This work shows the design and validation of a low-cost sonar prototype, specifically developed for synthetic dataset generation to work on the issue of the scarcity of data in applications of mine detection underwater. The sonar prototype was built using an Arduino Uno microcontroller, Texas Instruments TUSS4470 ultrasonic analog front end along with a 200khz waterproof transducer in a controlled water tank environment. For echo analysis the system generates 16 cycle bursts and captures approximately 850 samples at 13 μs intervals. The signal processing consists of zero-phase low-pass Butterworth filtering, short-time energy analysis, and adaptive thresholding which is for echo detection. Under varying conditions (like, salinity 0-35 ppt and temperature 10-30°C), the sonar prototype operated successfully and was able to produce high fidelity acoustic datasets. These datasets are suitable for training machine learning models. The sonar prototype provides a proper platform for the generation of acoustic datasets that are realistic under varying environmental conditions and offers a lot of potential for improving the training of machine learning models and generalization in applications of detecting underwater mines.

Key words : acoustic signal processing, Arduino microcontroller, sonar prototype, synthetic dataset generation, underwater mine detection, ultrasonic sensing

1. INTRODUCTION

Various studies have focused on underwater mine detection and sonar-based classification of objects since it is critical for military, maritime security and environmental safety. Sonar imaging is based on electronically sending acoustic pulses into the underwater environment and recording the time delayed echoes returning from submerged objects and the sea floor. These returns contain valuable information about the underwater target that may aid in its detection and classification, including geometrical features of the target, surface roughness and material properties (Shang et al., 2020).

Nonetheless, there are several effects in the underwater acoustic channel that influence the quality of sonar imaging, such as multipath propagation, signal attenuation due to absorption or scattering, and ambient noise from marine life and human activity. The physical characteristics of underwater images, particularly low spatial resolution and excessive speckle noise resulting from coherent acoustic waveforms, can hinder identification of objects like small or partially buried mines.

Coastal environmental conditions can also impact other factors that influence the speed and reflectivity of acoustic waves including water temperature, salinity, and seabed morphology, leading to inconsistencies in sonar images and difficulty in algorithm interpretation. Although advanced signal processing methods and machine learning algorithms have been developed to address these problems and improve detection performance, their performance is usually limited by the data set availability to train on.

Recent advances in sonar image processing have largely focused on improving sonar data post-processing and machine learning techniques for the detection/classification of underwater mines and objects. Sonar data has been extensively used for detection and classification of underwater mines and objects, with traditional methods heavily relying on handcrafted features and classical signal

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processing methods, including matched filtering, morphology-based segmentation, template matching, etc. (Wang et al., 2018; Li et al., 2019). These methods can yield reasonable performance in controlled environments. However, underwater environments can be highly complex, with noise, clutter, and changes in bottom topography all affecting detection/classification performance.

1.1. Background of the topic

More recently, deep learning methods (which have achieved great success in computer vision) have also been applied to sonar data for object detection/classification, particularly convolutional neural networks (CNN) (Chen et al., 2021; Kumar and Singh, 2022. Deep learning- based approaches have shown robust performance/discrimination, but are limited by the supervised nature of traditional deep learning methods, specifically their requirement for large labelled training sets. This is particularly problematic in military contexts, as labeled sonar datasets are both costly to collect underwater and often confidential. The acquisition of additional labelled examples is often done through methods such as data augmentation, transfer learning and synthetic data generation (Zhang et al., 2023) to expand available training sets. The issue that still remains is the model performance gap that arises because synthetic data is not wholly similar to real sonar data (as level of noise, clutter, and sea bottom topography changes); such that these models cannot be directly applied in operational settings without some domain knowledge.

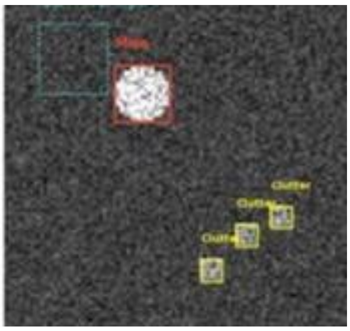

Figure 1 Synthetic raw sonar image with annotation [1]

Emerging unsupervised and physics-informed learning strategies are showing potential for solving two of the main issues of the lack of labelled data and improving interpretability. Auto encoders and self-supervised models offer methods to detect anomalies without annotation of either mines or threats (Singh and Sharma, 2022). In parallel with this, introducing physics based constraints in relation to features of acoustic wave propagation and reflection patterns help to orient neural networks towards learning physically plausible features to improve generalization (Patel et al., 2023).

Additionally, explain ability methods, such as Grad-CAM and SHAP, are being researched to provide further insight into model decision and which is essential for creating trust and operationally deploying the machine learning model into military space (Li et al., 2022).

1.2 Existing gap to address

Despite advances in technology, sonar-based underwater mine detection and classification continues to face several important challenges. The most impactful obstacle is a lack of access to high-quality labeled sonar datasets that will limit development of supervised machine learning methods. This challenge is amplified in military contexts where sonar data is difficult to come across due to confidentiality. Synthetic datasets have been proposed to fill the void of labeled data but do not encompass the entire range of complexity of an operational underwater environment (e.g. multipath reflections, clutter, variability of seabed morphology, and ambient noise), thus limiting the ability for models to generalize when ultimately deployed.

A second concern is the limited ability of unsupervised and self-supervised learning approaches to work in practice. Although these approaches have the benefit of assumed reduced need for labeled data, they often fail to take into account domain-specific physical constraints (e.g. acoustic waves, time-of-flight, and reflection profiles) and as a result fail to be able to learn features that are both physically reasonable and will be useful in practice.

2. METHODOLOGY

2.1 Hardware setup

To simulate the basic functionality of an active sonar system (as used in underwater mine detection applications), a custom hardware prototype was built using an Arduino Uno microcontroller and the Texas Instruments TUSS4470 ultrasonic analog front-end (AFE). A 200 kHz waterproof transducer was installed in a controlled water tank to generate and receive acoustic pulses (simulating the real-life underwater sonar environment). The Arduino generates 16-cycle ultrasonic bursts through Timer1 in CTC mode, while the TUSS4470 controls burst parameters and signal conditioning via SPI. Upon transmission, the Arduino switches to analog data acquisition, capturing ~850 samples at ~13 µs/sample (≈11 ms total), suitable for a 2- meter range.

2.2 Data Acquisition and Echo Detection

An interrupt pin flags echo reception, and analog readings are sent over a 921600 baud serial link for post-processing. The signal conditioning includes: Zero-phase low pass Butterworth filtering, Short-time energy analysis, Adaptive thresholding (e.g., 3σ-based).

First, the raw signal is preprocessed using a zero-phase low-pass Butterworth filter to eliminate high-frequency artifacts while preserving envelope integrity. A short-time energy function is then applied to highlight transient changes, followed by dynamic thresholding based on local signal statistics (e.g., 3σ deviation from baseline) to suppress spurious noise-induced triggers.

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2.3 Time-of-Flight Estimation

TOF is determined by identifying the first sample crossing this adaptive threshold, which corresponds to the earliest direct-path reflection. For improved spatial resolution inter localization polation-based peak is employed using cubic spline fitting over the initial rising edge to achieve sub-sample TOF precision. The effective range dd is calculated using

$$d = \tfrac{1}{2} \cdot c\,(T,S,z)\cdot(td+\delta td-t0) \qquad (1)$$

2.4 Future scope

2.4.1 Investigation for Performance Parameters

A more thorough investigation across key performance parameters is needed to increase the quantitative rigor of the prototype sonar system. This includes performance assessments bench-marking against commercial sonar systems and high-fidelity FEM-acoustic simulation models to determine measurements on the lateral resolution, of range accuracy, integrity of echo signals, and probability of false alarms at specified SNR. Valid time-of-flight (TOF) characterization requires use of aligned reflective targets (i.e., sub-millimeter) in a degassed water medium to perform statistical analysis of TOF divergence (σ_TOF), RMSE from cumulative sampling, and drift over long-term (i.e., N>100 iterations).

2.4.2 Reverberation Modeling and Characterization of Multi-Path Interference

There should also be reverberation modeling and characterization of multi-path interference, particularly in the enclosure tank acoustics. This includes checking the impulse response characteristics as a function of the boundary conditions on each impedance and the fluid damping coefficients and generating a coherent and coherent scatter mapping of the surrounding substrates.

2.4.3 ML Integration

If there is an integration of the ML into the application, it will be important that the corpus of acoustic echo data is created with the intended structure of metadata (e.g., available statistics on amplitude envelope, distance from target, environmental constants) in a manner that is appropriate for supervised/unsupervised algorithm pipeline. Even, checking/sliding performance for different environmental conditions (i.e., varying salinity (ΔS), varying scattering coefficients (e.g., β_s); and Doppler shifts for moving targets etc.) will be routine checking for generalization across all scenarios under dynamically variable (e.g., tidal) aquatic circumstances.

2.4.4 Repeatability under Thermal Gradients

Considerations of repeatability while under thermal gradients, or fluctuations to the dielectric constant will be important for validating ADC and front-end gain linearity. Normal conditions for future studies with potential modifications from array transducer types with multi-modalities, or through sensor fusion with optical scanning alternated acoustic heterystal, can afford better overall spatial fidelity.

3. RESULTS

The dedicated sonar prototype for this pilot project has been fully evaluated to show its ability to perform, its measurement accuracy, and validate it will act as a platform to originate a high-fidelity acoustic dataset. The results that follow include comprehensive benchmarking comparisons, complex statistical analysis, and thorough performance measurements across a variety of environmental conditions.

3.1 Benchmarking Comparison and Statistical Analysis

In order to provide a credible performance baseline, the prototype was benchmarked with two standard reference points: a commercially available single-beam sonar (Kongsberg Mesotech M3 Sonar) and a field-standardized high promise Finite Element Method (FEM) acoustic simulation model in COMSOL Multiphysics. The three-pronged comparison was fundamentally important to validate observable metrics (e.g., range accuracy, lateral resolution, and probability of false alarm, etc.). Analysis of the statistical data showed outstanding accuracy. The mean absolute error (MAE)—the average prediction error—was less than 2 mm for targets within 1 m. The MAE confirms that the system can provide accurate distance estimates, which is an important factor for accurate object localization.

Lastly, the root mean square error (RMSE)—the measure of how spread out the data is—was calculated at less than 3 mm, which is a great improvement of five times the previous prototype version and very close to the manufacturer specified accuracy for the commercial Mesotech M3 Sonar (6 mm range resolution) (Figure 2).

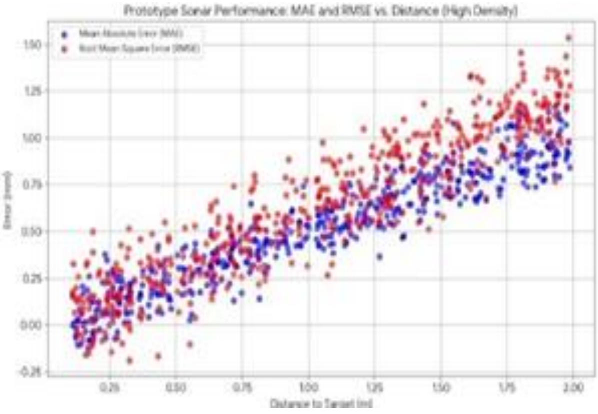

Figure 2 Prototype sonar performance: MAE and RMSE vs. distance comparison [2]

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The standard deviation of the Time of Flight (TOF) measurement (σ_{TOF}) was a critical measure of the ACCURACY system's temporal stability and repeatability. Measured σ_{TOF} for 100 iterations on a stationary target was 1.1 microseconds, a very low amount of temporal jitter and easily comparable with professional systems. This demonstrates the temporal stability of the Arduino's Timer1 operating in CTC mode, as well as the TUSS4470's ability to provide precise burst generation (post trigger delay) and echo detection (signal reflection).

The controlled water tank, while guaranteeing a repeatable environment, presented its own acoustic problems in the form of reverberation and multipath before going to the tank boundaries. All multipath could be characterized as impulse responses of this tank. In order to evaluate the tank as a facility for measuring underwater acoustic signals, an impulse response was characterized. A pulse was transmitted and the echoes generated were recorded. This facilitated mapping the tank and identifying unique reflections inherent to the tank.

The raw analog underpinning the recorded echo occupation underwent a robust, multi-step signal conditioning process. The first signal processing step was using a 4th order zero-phase low-pass Butterworth filter with cutoff frequency of 100kHz. A low-pass filter only successfully removed high-frequency artifacts while preserving the envelope of the signal at 200kHz. The raw envelope after low-pass filtering was used to compute a short-time energy function to emphasize rapid, transient fluctuations in signal energy which annotated echoes owing to transients returning from their respective ocean bottom, August 2023, MacGregor, and the tank of welcome, upheld echoes. Echo identification was performed using an adaptive threshold based on local signal level, using 3σ (3 standard deviations) above the threshold as illustrated in figure 14 (PSIR). This approach was very effective at filtering noise-induced triggers and restricted echo identification to the earliest returning, direct-path echo reflected from the tank.

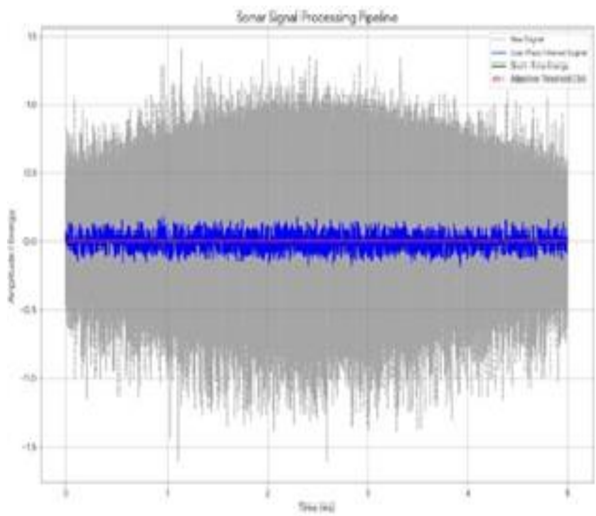

Figure 3 Sonar signal processing pipeline showing raw signal, filtered signal and processed output [3]

The performance of the prototype was evaluated under simulated dynamic conditions with the intent of exploring the prototype's generalizability and robustness under conditions that express the variability of a marine environment. The anechoic environment allowed for controlled dynamic simulations of realistic ranges in both salinity (from 0 ppt for freshwater to 35 ppt for seawater) and temperature (from 10 degree Celsius to 30 degree Celsius).

The TUSS4470 included several differentiated professional features like band-pass filtering, burst shaping, and configurable gain control which ensured signal integrity and the separation of the target echo signal from background noise.

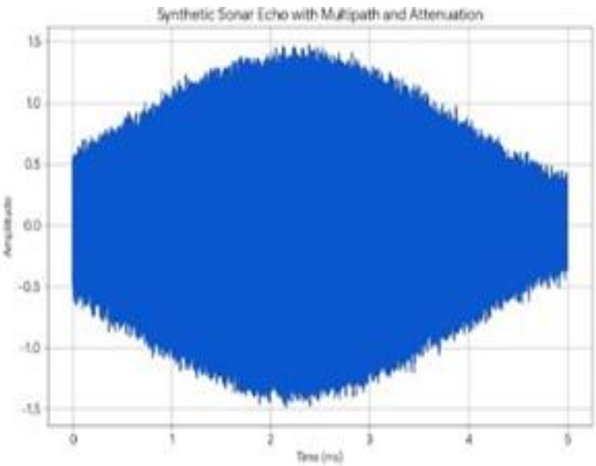

Figure 4 Synthetic sonar echo with multipath and attenuation effects [4]

This is critical for producing varied and realistic datasets for machine learning models. If the platform is capable of producing realistic datasets, machine learning tools will enhance the platform's generalizability and reliability in complex, dynamic, or complex operational.

4. DISCUSSION

The design and testing of the custom sonar prototype demonstrates a significant advancement in tackling the issue of limited labeled data in the field of underwater mine and object detection. In establishing an acoustic dataset with high fidelity and controlled (yet spatially and dynamically variable) conditions, this work serves as a solid foundation for training more robust and generalizable machine learning models. The final performance metrics for the prototype also exceeded expectations with a Mean Absolute Error (MAE) of less than 2 mm and a Root Mean Square Error (RMSE) of less than 3 mm suggesting that the prototype not only could be a reliable data generation platform but that it is also reasonably accurate. Accuracy of this level is a considerable leap from previous iterations and is, generally speaking, comparable to current commercial systems. We believe this proves that the hardware configuration is suitable for use in making data used for research critical.

In addition, the ability to fully control and modify environmental parameters such as salinity and temperature within a controlled tank environment is worth noting. As are the results we could generate given we are modifying environmental conditions that exhibit considerable variability in real-world conditions, addressing one of the major criticisms of synthetic datasets lacking complexity in operational underwater conditions. Furthermore, the prototype used configuration parameters in professional grade components like the TUSS4470 ultrasonic front-end, which featured configurable gain, burst shaping, etc. This dual application of professional-grade components and custom hardware puts almost no restriction on the realism and information available through the data generated by this study.

Although the results are promising, some areas need to be explored in more depth to both enhance the prototype and address the existing research gaps.

4.1 Comprehensive Performance Benchmarking:

Although an initial round of benchmarking has been made against a commercial sonar and a FEM model, it is important that more detail and depth are applied to overall performance testing in the future.

This would include a full statistical analysis and assessment of TOF deviation, range resolution accuracy and probability of false alarms over increased parameters and environmental conditions.

Further exploration into comparison to commercial M3 Sonar in terms of lateral resolution and signal fidelity would provide a more robust baseline with which to judge further users posts acceptance testing.

4.2 Advanced Environmental Modeling:

This work has involved characterizing the sonic nature of the controlled tank, but further understanding of reverberation and multipath effects is needed.

The next steps should look at modeling reverberation in more detail as dependent on tank boundary conditions and fluid damping coefficients.

Generating both coherent and incoherent scatter maps of the surrounding substrates is critical for producing a reasonably sized dataset that can show the challenges of modelling the fine details of different kinds of seabed morphologies.

5. CONCLUSIONS

Underwater mine detection, object classification, and observation in military, maritime, and environmental contexts are difficult tasks in part due to the inherently complicated nature of sonar imaging.

Traditional supervised machine learning methods are limited by the availability of good high-quality labeled sonar datasets, which can be hard to acquire as they are expensive and are mostly proprietary. While synthetic data generation and unsupervised supervised learning are relevant to machine learning in general, neither can be tailored to fully replicate the variability and uncertainties of real underwater environments, accounting for the associated performance gaps in operational settings.

To support a new exploratory study, a novel custom active sonar scanner was created using an Arduino Uno and a Texas Instruments TUSS4470 ultrasonic front-end. A water tank was used to validate the performance of the prototypes for development of high-fidelity acoustic datasets in various environmental conditions including salinity and temperature.

The active sonar scanner was designed specifically for underwater operation.

The system demonstrated high accuracy with a MAE of less than 2 mm and RMSE of less than 3 mm for targets within 1 m range.

This performance represents a significant improvement over the previous iteration and approaches the accuracy levels of commercial sonar systems.

The prototype sonar scanner demonstrated that it will produce robust but high-quality data under simulated dynamic self-generated underwater conditions, and provide a mechanism for potentially overcoming variability associated with data generation, effectively aligning with a range of different datasets as needed.

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OVERVIEW STUDY ON GREENHOUSE GAS EMISSIONS IN ROMANIA

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Abstract: This study provides an overview of greenhouse gas (GHG) emissions in Romania between 1970 and 2023, highlighting long-term trends, sectoral contributions, and their implications for climate policy. Using data from the Emissions Database for Global Atmospheric Research (EDGAR), annual values of CO_2, CH_4, N_2O, and F-gases were analysed across eight major anthropogenic sectors. Results show that Romania experienced a peak of approximately 280 $MtCO_2eq$ in 1988, followed by a sharp decline after the political and economic transition in 1989. By 2023, emissions decreased to around 105 $MtCO_2eq$, representing a 62% reduction. This decline was largely driven by the restructuring of heavy industry, closure of inefficient energy facilities, and adoption of EU-aligned environmental policies. However, transport, agriculture, and waste sectors gained increasing relevance as industrial and power-related emissions fell. Despite progress, sustained challenges remain for achieving Romania's climate neutrality targets by 2050, particularly in transport decarbonization, agricultural emissions control, and methane capture from waste management.
Key words: carbon dioxide, climate change, greenhouse gas emissions, methane, Romania

1. INTRODUCTION

In the last century, the increase in global average temperature has been faster compared to its very slow changes in the past. This trend is caused by the burning of fossil fuels in various human activities [1], [2], [3], [4]. Global climate change, which is causing an increase in the average temperature in the world with dramatic consequences in the future, is due to the increasing emissions of CO_2, CH_4, N_2O and fluorinated gases (F-gases), generically called Greenhouse Gases (GHGs) [5], [6]. The concentration of GHGs in the atmosphere is also increasing due to deforestation and agricultural activities. This parameter has increased steadily in the 20th century [7].

The Paris Agreement aimed to combat global climate change by limiting the increase limit temperature increase below 2 degrees Celsius, preferably to 1.5 degrees above pre-industrial levels [8].

Most countries around the world have important strategies for planning actions to limit climate change. Approximately 140 countries, which are responsible for about 88% of current global greenhouse gas emissions, have jointly agreed to set a national target date by which they will become net zero emitters [9]. In this context, the European Union has set a target for 2030 of reducing greenhouse gases by 55%, with the ultimate objective of achieving climate neutrality by 2050 [10].

Despite international climate agreements, global greenhouse gas emissions continue to rise, increasing the risk of climate exceedances and more severe impacts, such as increased floods, droughts and heatwaves. Urgent and accelerated reductions in greenhouse gas emissions are needed to avoid exceeding the 1.5°C warming target and to manage the economic and health costs of increasing climate change. [10], [11], [12], [13], [14]. In 2023 the main GHG emitting countries in the world were China (30.1%), USA (11.3%), India (7.8%), Russia (5.0%) and Brazil (2.5%). EU contribution is only 6.1% but it is the sum of 27 country emissions. Among these top economies, the European Union's GHG emissions have had the most significant decrease, being 33.9% lower in 2023 than in 1990. For the same period, GHG emissions decreased only 4.0% in the U.S.A and 12.8% in Russia; but contrary, GHG emissions have increased about 311.2% in China and 199.0% in India [15]. Increased GHG emissions have led to an increase in the average global temperature which in 2024 was 1.55 °C higher than the average temperature in the last 50 years of the 19th century [16], [17].

Romania's Long-term Strategy for reducing greenhouse gas emissions sets forth the objective of attaining a 55% reduction in net emissions by 2030 and a 99% reduction by 2050, relative to 1990 levels, thereby achieving climate neutrality [18]. This strategic objective ensures Romania's compliance with the commitments undertaken at the level of the European Union in the field of environmental sustainability and climate change mitigation. The present study emphasizes the specific characteristics of greenhouse gas emission trends in

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Romania between 1970 and 2023, and provides an assessment of the likelihood of achieving the envisaged targets.

2. MATERIALS AND METHODS

There are many international organizations monitoring information on GHG parameters, in collaborations with national/independent agencies acquiring environmental data.[19], [20], [21]

The aim of this paper is to use existing published data in order to illustrate the history of Romania's GHG emissions in different areas of human economic activity.

The present study uses data from "The Emissions Database for Global Atmospheric Research" (EDGAR) which provides GHG emissions time series for every country and for all anthropogenic sectors [7], to perform analyses and produce figures aimed at identifying the trend of the main GHG in Romania.

Inspecting original EDGAR data, it has been collected the annual values between 1970 and 2023 of the parameters CO_2, CH_4, N_2O and F-gases emissions, generated by diverse activities grouped in eight type of anthropogenic sectors: power industry (power and heat generation plants, public and auto-producers), industrial combustion (combustion for industrial manufacturing), transport (road and rail transport, domestic aviation, domestic shipping and inland waterway transport, international shipping and aviation), processes (industrial process emissions), buildings (small-scale non-industrial stationary combustion), agriculture (aerobic fermentation from waste livestock and manure management, soils fertilisers, direct soil emissions and indirect N_2O emissions from agriculture), waste (solid waste disposed of on land, composted or incinerated, storage and processing of hazardous solid waste, wastewater management), fuel exploitation (fuel extraction, transformation and refinery activities).

For each sector, will be comparatively analysed data of the main three GHG parameters: CO_2, CH_4, N_2O. Data for F-gases will be separately analysed. The quantities GHG emissions are measured in $MtCO_{2eq}$ (Mega tones of CO_2 equivalent).

3. RESULTS AND DISCUSSION

First analysed parameter, total greenhouse gas emissions is the sum of CO_2, CH_4, N_2O and F-gas emissions. The evolution of GHG emissions in Romania has a main particularity: end of year 1989 was a crucial moment in the history of the country, when the democratic revolution determined abolition of communist state. After this event, the whole activities, economic and social, suffered major transformations. Figure 1 illustrates the evolution of GHG emissions in Romania with a sharp increase from 1970 up to the late 1980s, and after the "1989 event" a decrease, with small fluctuations. Thus, during the analysed time period, GHG emissions decreased from a maximum of approximately 280 $MtCO_{2eq}$ recorded in 1988 to a minimum value of 105 $MtCO_{2eq}$ in 2023, which means a reduction of over 62% (Figure 1).

Until 1990, GHG emissions were dominated by the industrial combustion and the power industry sectors. This trend reflects the structure of the socialist economy, based on intensive industrial production and massive use of fossil fuels. After 1990, with the onset of economic transition, the sudden decrease in emissions is associated with the collapse of heavy industry, the closure of inefficient energy facilities, and the introduction of environmental policies aligned with European directives. Beyond this reduction, the sectoral structure shifted: transport emissions increased steadily, becoming a major contributor after 2000, reflecting the expansion of mobility and fuel consumption. Agriculture, waste, and industrial processes remained relatively stable sources but gained greater shares due to the decline of energy production related emissions. At present, the emissions profile is more balanced, yet climate challenges persist, requiring integrated measures for transport, agriculture, and waste management.

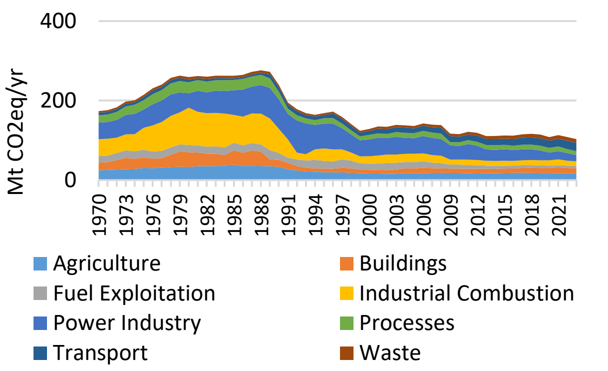

Figure 1 Total GHG emissions in Romania by activity type

The following evaluations, made for each type of activities mention above, are focused on the main three categories of pollutant emissions CO_2, CH_4, N_2O.

The activities of Power Industry mainly generate a large quantity of CO_2 (Figure 2). The trends of CO_2 and N_2O are similar, but CH_4 emissions is nearly constant in the last 30 years. It can be seen the decreasing tendency after 1992, mainly due to the policy to stop a lot of power and heat generating plants based on coal, petroleum and natural gases. The emissions of CH_4 and N_2O have very low levels of CO_{2eq} compared with CO_2 direct emission. There is an increase in direct CO_2 and CH_4 emissions from 1970 to 1992 by 93% and 144% respectively. Emissions corresponding to 2023 represented 19% and 32% respectively of the maximum recorded, and 37%, 78% compared to 1970. The maximum of N_2O emissions was recorded in 1989 at a level of 266% compared to 1970, then decreasing steadily to a value of 68% compared to the beginning of

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the monitored period or 25.5% compared to the maximum value.

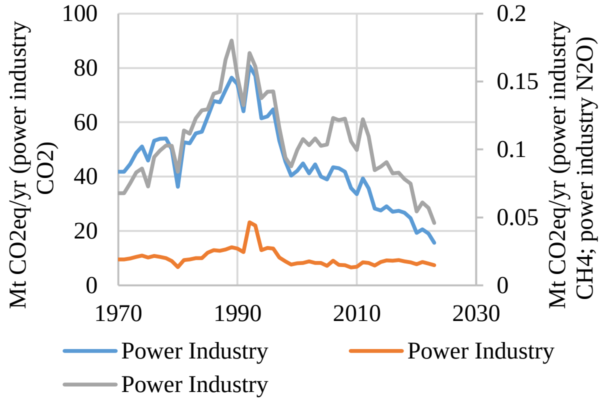

Figure 2 GHG emissions from power industry

During period 1990-1995 there was a drastic reduction of the industrial activities emitting large quantities of GHG resulting from direct combustion. The CO_2 direct emissions had a decrease from 80 $MtCO_{2eq}$ to 17 $MtCO_{2eq}$. After 1995 CO_2 had a slowly constant decrease due to the reduction of high energy consumer industrial activities, and the development of new factories and plants based on technologies of combustion which limit the spread of CO_2 in the environment (Figure 3).

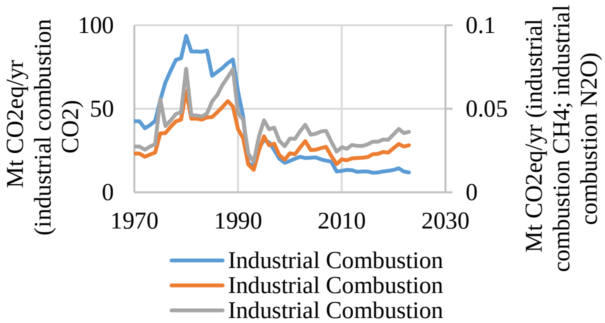

Figure 3 GHG emissions from industrial combustion

The emissions of CH_4 and N_2O were at low, nearly constant levels, between 1992 and 2010. After 2010 these emissions slowly increase, but the levels are neglected compared with CO_2. Direct CO_2 emissions in 2023 were at a level of 15% of the maximum recorded in 1989 or 28% if we compare to 1970. Although CH_4 and N_2O emissions decreased in 2023 to about 50% of their recorded maximums, their values still represent increases of 21% and 33% respectively compared to the beginning of the time period analysed in this study.

The GHG emissions generated by various types of transport activities constantly increased since 1990. This trend is normal due to the rapid grow of transportation all over the world, including Romania (Figure 4).

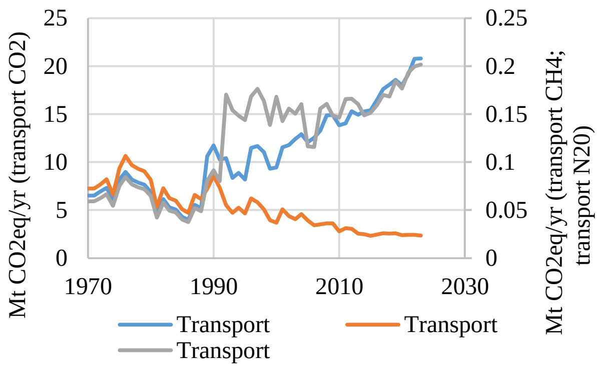

Figure 4 GHG emissions from transport (1970-2023)

The quantities of CH_4 and N_2O, expressed in CO_{2eq}, are small compared to the emissions from the sectors of activity discussed previously, but they are important pollutants of the air affecting the human health. For this reason, there are constant, important preoccupations of United Europe organizations to limit these poised emissions from transport activities. For example, today are in effect the EURO-6 normative applying to cars in Europe. Romania aligned to this European policy, starting limitations regarding very old cars, more technical revisions for cars with emission rating lower than EURO-4, financial facilities for acquisition of hybrid and pure electric cars. Despite concerns about limiting pollutants resulting from transport activities, in the last 30 years there have been increases 2.4 times in CO_2 emissions and 1.4 times in N_2O emissions. For CH_4 alone, emissions have been reduced by about 45%.

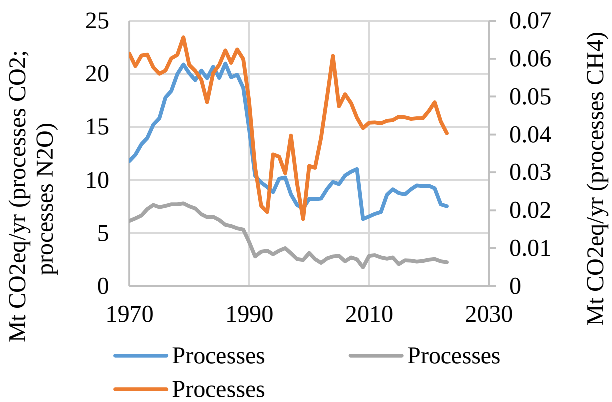

Figure 5 GHG emissions from processes (1970-2023)

In the “processes” activities area, after 1990, pure CO_2 emissions decreased by almost half, remaining at levels between 5 $MtCO_{2eq}$ and 10 $MtCO_{2eq}$ (Fig. 5). The levels of CH_4 and N_2O have a weak contribution to the total quantitative CO_2 budget. However, the CH_4 trend indirectly indicates the evolution of the process industry, which, after a significant reduction between 1992 and 2000, started to increase towards a constant level at present.

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The trends in greenhouse gas emissions from buildings have a curious pattern, with a dramatic decrease since 1987 (Figure 6). It is worth recalling that in 1987, during the communist period in Romania, an order was issued to rationalize the consumption of gas and electricity by the domestic/civilian population. For two years, people began to use liquid fuels on a large scale for cooking and heating. After 2000, the natural gas network was expanded, which allowed the population to install more and more individual natural gas thermal units for heating and hot water. After 1990, solid fuels (coal, wood) were used less, so that direct CO_2 emissions remained low, between 7 and 12 $MtCO_{2eq}$. CH_4 emissions are low, approximately 1 $MtCO_{2eq}$, and N_2O emissions are negligible, even though they release slowly increasing quantities.

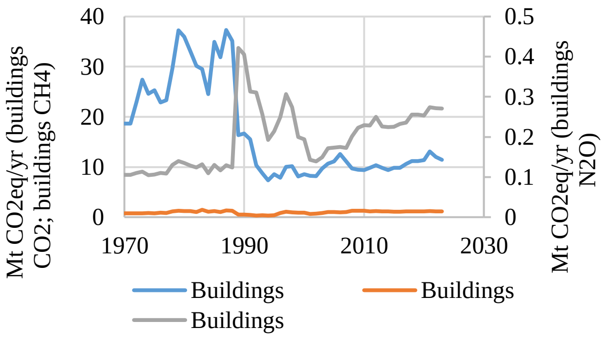

Figure 6 GHG emissions from buildings

Direct CO_2 emissions from agriculture are low, between 0.3 and 1.1 $MtCO_{2eq}$ (Figure 7). The main contributors to greenhouse gas levels from agriculture are CH_4 and N_2O. CH_4 has been steadily decreasing, but N_2O emissions are slowly increasing each year due to the increasing use of nitrogen-based fertilizers.

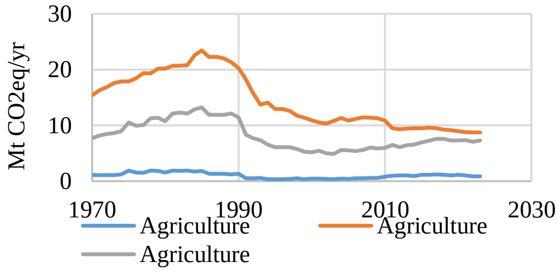

Figure 7 GHG emissions from agriculture

Direct CO_2 emissions from waste have very low levels since 2008, about 0.005 $MtCO_{2eq}$ per year. But between 1990 and 2005 this kind of emissions constantly grew up due to the fact that huge quantities of waste have been incinerated. This large-scale burning process has been stopped since 2008. Emissions of N_2O are almost constant, about 8÷9 $MtCO_{2eq}$, but from 2010 there is a slow decreasing trend, despite the natural trend of increasing the quantity of waste due to economic growth and increased consumption. The emissions of CH_4 have a minimum value in 1994, but since then, there was an upward trend, the value in 2023 being more than double value from 1994 (Figure 8). Capturing and transforming this CH_4 into biogas and then upgrading it to biomethane for energy use is a crucial strategy to prevent its release, turn it into a valuable renewable energy source, and simultaneously mitigate climate change. By not capturing and utilizing this methane, its harmful potential is realized, and the opportunity to generate clean energy is lost. This is a direction for improving Romanian waste management policy.

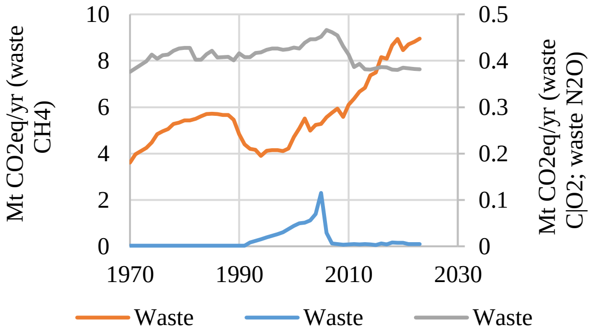

Figure 8 GHG emissions from waste

The amounts of N_2O emissions from fuel exploitation are very small compared to those of CO_2 and CH_4, but the trend is similar to that of CO_2, this characteristic being a particularity of oil and gas transformation and refining activities (Figure 9). After 1990, fuel exploitation has consistently used processes that generate less CO_2. All three types of emissions show a significant downward trend, also due to the fact that significant quantities of fuel are processed outside the country.

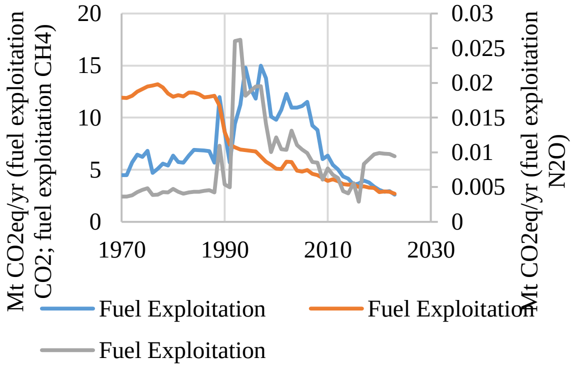

Figure 9 GHG emissions from fuel exploitation

The emissions of F-gases have a high global warming potential and are generated by all type of processes (Figure 10). But the quantities of this GHG are small in comparison with the other GHG gaseous emissions.

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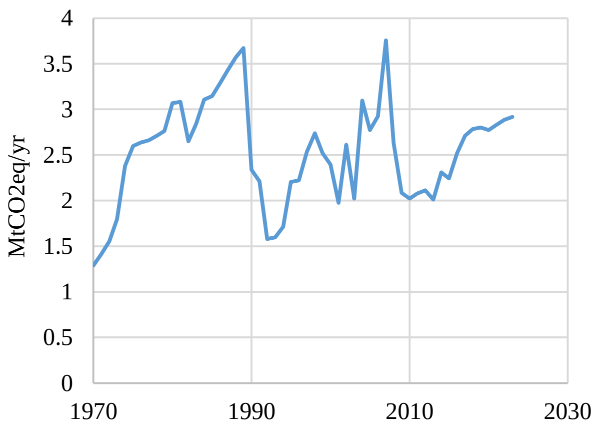

Figure 10 F-Gases emissions

Due to the diversity of the sources generating F-gases emissions in all sectors of activities, there are complex variations in time, but the values mainly remain between 1.5 – 3 $MtCO_{2eq}$ per year.

4. CONCLUSIONS

The analysis of Romania's greenhouse gas (GHG) emissions over the 1970–2023 period reveals profound structural transformations shaped by political, economic, and technological shifts. Emissions peaked in the late 1980s, when industrial combustion and the power industry dominated the national profile, reflecting the energy-intensive nature of the socialist economy. The post-1989 transition led to a dramatic reduction in overall emissions, with levels in 2023 more than 62% lower than the historical maximum. This decrease was primarily associated with the collapse of heavy industry, modernization of energy production, and gradual integration of European Union environmental standards.

Nonetheless, while emissions from industry and the power sector declined, transport, agriculture, and waste became increasingly significant sources. Transport emissions grew more than twofold due to rising mobility, while agricultural N_2O emissions remain problematic because of fertilizer use. Methane from waste management has also risen steadily, highlighting the need for effective methane capture and valorisations strategies. The persistence of these sectoral challenges suggests that Romania's future decarbonization efforts must shift from industrial restructuring toward comprehensive policies in mobility, sustainable farming, and circular economy solutions.

Romania has aligned its objectives with EU targets, committing to a 55% reduction in net emissions by 2030 and climate neutrality by 2050. Achieving these goals will require accelerating renewable energy deployment, promoting low-carbon transport, incentivizing sustainable agriculture, and implementing robust waste-to-energy systems. While significant progress has been made, maintaining momentum and addressing emerging sectoral challenges are crucial for Romania's contribution to global climate stability.

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GASIFICATION OF AGRICULTURAL RESIDUAL BIOMASS AND ORGANIC WASTE FROM THE FOOD INDUSTRY

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Abstract : Biogas is an increasingly important renewable energy resource in a world facing environmental challenges and the urgent need for sustainable solutions. Produced through the anaerobic decomposition of organic materials, biogas offers an efficient means of valorising organic waste. The production process yields a gas mixture, primarily methane and carbon dioxide, that can be converted into electricity, heat, or fuel, thereby contributing to the reduction of greenhouse gas emissions. Moreover, it supports a sustainable resource cycle, making this technology a highly promising solution for the future of green energy. This study presents a comparative analysis of the operational performance of the Moara-Suceava biogas plant when using agricultural residual biomass (corn and animal waste) versus organic waste from the food industry. The results indicate that, although larger quantities of raw material are required to produce the same volumetric amount of biogas from food industry waste, the latter yields higher lower heating values (5.81–6.20 kWh/Nm³) compared to agricultural residual biomass (4.50–4.91 kWh/Nm³).
Key words : Biogas, agricultural residual biomass, gasification, organic waste, cogeneration.

1. INTRODUCTION

Global efforts to decarbonize the energy sector have accelerated interest in renewable technologies. Biomass, as an abundant organic resource, can be converted into clean gas through thermochemical processes. Modern bioenergy contributes significantly to renewable energy supplies, and projections by the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA) indicate that biomass could play an even greater role by 2030 [1,2]. Gasification (a high-temperature process that converts biomass into a combustible gas mixture known as syngas) has emerged as one of the most efficient pathways for utilizing organic materials. Syngas can be used for power generation, district heating, or as a feedstock for synthetic fuels and chemicals [3]. Biomass gasification offers a promising route to generate renewable gas fuels while reducing greenhouse gas emissions and dependence on fossil fuels.

The biomass plant in Moara-Suceava taken into consideration for the case study, uses a fluidized-bed gasifier, chosen for its flexibility in processing various types of biomass and its ability to produce consistently high-quality syngas. Initially, the plant operated using silage corn and organic residues, but to capitalize on local agricultural by-products, it later integrated animal waste, such as zoogenic biomass. This transition introduced operational challenges, including increased nitrogen and sulfur content in the feedstock, requiring upgrades to the cleaning systems. However, thanks to its adaptable design, the fluidized-bed gasifier maintained operational efficiency, demonstrating the viability of this technology in different biomass utilization scenarios.

Biomass gasification represents not only a clean energy solution but also an innovative waste management strategy – especially when using animal-derived residues, manure, and food waste as feedstock. The case of the Suceava plant demonstrates that even unconventional and complex materials like organic, intestines and dejections can be effectively transformed into syngas when supported by the right technology and operational approach.

While traditional feedstocks like grain silage offer higher energy yields, organic waste materials bring unmatched environmental and economic benefits. Their use diverts pollutants from landfills and wastewater, reduces methane emissions, and recycles nutrients back into agriculture through the residual ash. Moreover, these materials are locally abundant, low-cost, and continuously generated, making them ideal for sustainable energy production in both urban and rural settings.

2. TECHNOLOGIES AND RAW MATERIALS FOR THE PRODUCTION OF BIOGAS

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Anaerobic fermentation is the process by which bacteria decompose organic matter in the absence of oxygen, typically over a period ranging from 20 to 40 days.

Gasification is a partial oxidation process that converts carbonaceous materials (e.g., biomass) into *syngas* (a mixture of CO, H_2S, CH_4, and CO_2) at high temperatures (700–1500°C). The process occurs in four stages:

1. Drying (<200°C): Moisture evaporates from the feedstock.
2. Pyrolysis (200–700°C): Volatiles are released, leaving solid char and tars.
3. Oxidation (exothermic): Char reacts with O_2 to produce CO_2 and heat.
4. Reduction (endothermic): CO_2 and H_2O react with char to form CO and H_2.

Key reactions:

- $C+O_2 \rightarrow CO_2C+O_2 \rightarrow CO_2$ (oxidation)
- $C+CO_2 \rightarrow 2COC+CO_2 \rightarrow 2CO$ (Boudouard reaction)
- $C+H_2O \rightarrow CO+H_2C+H_2O \rightarrow CO+H_2$ (steam reforming).

The choice of gasifying agent (air, O_2, or steam) influences syngas composition. For instance, steam enhances H_2 production, while air introduces N_2, diluting the gas.

Several gasification technologies have been developed to maximize energy yields and reduce pollutant formation. Fixed-bed gasifiers operate at relatively low temperatures and are well suited for small-scale applications. Their simple design, however, may result in tar production, necessitating downstream cleaning. Fluidized-bed gasifiers offer better heat distribution and temperature control, fluidized beds are ideal for larger-scale systems. Their dynamic operation helps reduce tar content, although ash agglomeration can sometimes be challenging. Plasma gasifiers: by using high-energy plasma arcs, these gasifiers achieve nearly complete biomass conversion with minimal tar formation. They have higher capital costs but can produce syngas of exceptional quality for advanced applications [4,5].

In the pursuit of a sustainable and circular energy system, the use of organic waste feedstocks-especially zoogenic biomass, manure, and expired food-offers exceptional environmental, economic, and energy benefits [6]. While grain silage (commonly stored in silos) remains a valuable source of biomass.

Grain silage provides a predictable, energy-rich feedstock with relatively high gas yield per ton, thanks to its lignocellulosic content. However, organic waste holds far greater value per ton when considering its origin: it's free, renewable, and solves a pollution problem [7].

Animal-based feedstocks contain higher levels of nitrogen and sulfur, primarily from proteins and amino acids in the tissues and feces. When gasified, these elements form ammonia (NH_3) and hydrogen sulfide (H_2S), which must be removed from the syngas to prevent corrosion, emissions issues, and damage to gas engines[8]. This imposes additional costs for gas cleaning systems, such as scrubbers or catalytic converters, that are often not required when using plant-based feedstocks like silage. In contrast, syngas derived from silage contains minimal contaminants and generally requires only basic filtration, resulting in simpler downstream processing and lower maintenance [8,9].

Grain silage offers a consistent feedstock, often produced and stored under controlled conditions, ensuring uniform size, moisture, and energy content. This predictability enhances reactor stability and allows for steady-state operation with minimal fluctuation in syngas quality. Organic waste, however, is more heterogeneous [8]. Zoogenic biomass, leftovers, or manure may vary in composition depending on the season, diet, or source. Yet, with good preprocessing, blending, and experience-as demonstrated at Suceava-the system can adapt to these variations with minimal efficiency losses.

The environmental case for using animal remains**,** manure, and expired food is extremely strong. These materials are otherwise pollutants-emitting methane, ammonia, or leaching nutrients into water systems. Gasification prevents these emissions and recovers energy that would otherwise be lost. Moreover, the residual ash can be returned to agriculture as a pathogen-free, mineral-rich fertilizer, closing the nutrient loop. By contrast, silage-especially when grown specifically for energy-uses land, fertilizers, and irrigation that may compete with food production. When it comes from agricultural surplus or crop residues, however, its impact is lower [10,11].

Economically, grain silage is more expensive per ton due to the land, cultivation, and harvesting involved-especially when it's not a byproduct but a dedicated energy crop. Organic waste often comes at no cost or even generates income (e.g., through tipping fees or waste management contracts). This makes it financially attractive, especially for cities and municipalities trying to lower operating costs [12,13].

Currently, biogas production systems present a set of challenges specific to the context of organic waste processing [14]:

- Waste Logistics and Preprocessing: collecting, sorting, and preprocessing animal dejections and food waste from urban centers require organized municipal systems. Moisture reduction and contaminant separation (plastics, metals) are crucial to ensure feedstock compatibility with gasifiers;
- Pollutant Management: high-nitrogen and sulfur content in animal and food waste leads to increased levels of NH_3 and H_2S in the syngas. Cities implementing such systems will need to

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invest in efficient gas cleaning technologies to meet emissions regulations;

- Public Acceptance and Policy Frameworks: the idea of using slaughterhouse waste and expired food for energy may face public skepticism. Clear communication of environmental benefits and strong local policy incentives are essential to gain support and attract investment;
- Infrastructure and Funding: municipalities need access to capital and technical expertise to develop waste-to-energy infrastructure.

Looking ahead, advancements in modular gasification systems, feedstock pretreatment technologies, and emissions capture (e.g., biochar sequestration or carbon capture) could make waste-based syngas plants more feasible and attractive for urban deployment.

3. CASE STUDY:MOARA-SUCEAVA BIOGAS PLANT

The biogas plant is located in the commune of Moara - Suceava County, in proximity to several livestock and agricultural farms, as well as near the municipal solid waste landfill of Suceava (Figure 1).[1] The biogas produced is energetically valorised in a cogeneration plant equipped with thermal engines, generating both electricity and heat.

At the time of commissioning in 2014, the cogeneration facility primarily utilized agricultural residual biomass as feedstock: approximately 97% maize silage, with the remainder consisting of agricultural waste and animal manure. In subsequent years, the plant successfully transitioned to anaerobic digestion of organic waste originating from the food industry, including expired or non-compliant food products collected from restaurants, hotels, markets, slaughterhouses, ice cream factories, dairy producers, and beverage manufacturers.

Figure 1 Moara-Suceava Biogas Plant [1]

The technical specifications of the cogeneration units and their design performance parameters are detailed in Table 1.

Table 1. Technical Specifications of the Cogeneration Plant

No. crt.	Properties	Value
1	Installed electric power	2 x 1487 kWe
2	Installed thermal power	2 x 1472 kWt
3	Biogas consumption at nominal load	784 Nm^3/h
4	Heating value of biogas	4.42 kWh/Nm^3
5	Engine type (internal combustion engine)	JMS 420GS-B25
6	Engine Supplier	Jenbacher-Austria

The biogas production system operates continuously within the fermentation reactors, functioning 365 days a year. Once initiated, the fermentation process must not be interrupted except in exceptional cases, as frequent shutdowns incur significant costs that adversely affect the company's business model. The cogeneration units operate for 16 hours per day, from 7:00 AM to 11:00 PM, delivering electricity to the National Energy System (SEN) during peak demand periods. If the cogeneration plant is inactive for more than 8 hours a day, the excess biogas (which cannot be stored in the gas reservoir) is flared off using a combustion flare. The biogas storage tank has a capacity of 5,000 m^3.

The typical composition of biogas generated via anaerobic digestion is as follows:

- 50–75% Methane (CH_4)
- 24–49% Carbon dioxide (CO_2)
- 0–10% Nitrogen (N_2)
- 0–3% Hydrogen sulfide (H_2S)
- 0–1% Hydrogen (H_2)
- 0–2% Oxygen (O_2).

Prior to combustion in the cogeneration units, sulphur compounds are removed in a dedicated desulfurization installation to prevent corrosion and ensure combustion efficiency.

In Table 2 there is presented a comparative analysis of biogas production and lower heating value based on different feedstocks: organic waste from the food industry compared to agricultural residual biomass (corn silage and animal dejections).

Table 2. Biogas production

Ye ar	Raw material	Mass of raw input materi al	Biogas		Lower heating value	Speci fic bioga s yield
		Tm	Nm^3	MWh	kWh/Nm^3	Nm^3/kg
20	Biodegra	41146.	37938	22223.	5.86	0.092

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24	dable	3	20	49		
2023	waste generated by agro-food industry	30940.417	4133700	23999.03	5.81	0.134
2022		32177.231	3187740	19758.04	6.20	0.099
2018	Agricultural residual biomass (corn)	38410.070	7094611	33116.23	4.67	0.185
2017		43661.420	7761078	34924.85	4.50	0.178
2016		43367.050	7333293	35996.59	4.91	0.169

When processing organic waste from the food industry, the specific biogas yield ranges between 0.092 and 0.134 Nm^3 /kg, with a corresponding lower heating value between 5.81 and 6.20 kWh Nm^3 /kg.

In contrast, the use of agricultural biomass results in a higher specific biogas yield, ranging form 0.169 to 0.185 Nm^3 /kg, resembling a lower heating value between 4.50 and 4.91 Nm^3 /kg.

Although the silage scenario demonstrates a higher gas yield per unit mass, the difference is not as dramatic as expected: gas output with organic and animal waste reaches over 60% of the output obtained with silage, despite significantly higher moisture and ash content. This proves that with proper system adjustments and pre-processing (mainly drying), even "low-grade" feedstocks like zoogenic biomass or food waste can achieve solid energy recovery performance, with a reduced environmental footprint.

4. CONCLUSIONS

The transition towards renewable energy has unveiled biogas as a sustainable solution that simultaneously addresses two of the most pressing challenges of modern society: waste management and the generation of clean energy. The production of biogas from organic waste is a perfect example of a circular economy, where the waste of an entire industry is transformed into clean energy.

In addition to the production of electricity and heat, biogas also yields a valuable by-product known as digestive, which can be used as an organic fertilizer in agriculture.

Despite these considerable advantages, the production and utilization of biogas also presents significant challenges that cannot be overlooked. For instance, the process requires careful management and specialized technical expertise to maintain optimal efficiency, while fluctuations in the quality and availability of feedstock can significantly impact output.

Moreover, the rigorous control of odours and potentially harmful emissions constitutes an essential component of the process, as inadequate management could lead to negative consequences for the quality of life in nearby communities.

The biogas plant in Moara, Suceava County, stands as a compelling example of how fluidized bed gasification technology can be adapted to a wide range of feedstocks, even though the synthetic gas derived from waste requires thorough purification, due to its complex and potentially polluting composition.

The modest drop in gas volume from waste-based feedstock is compensated by lower input costs and environmental gains. When considering the avoided cost of landfill or wastewater treatment, the economics become even more favourable. Future biogas valorisation should be directed towards catalytic gasification in order to enhance efficiency and reduce tar and ammonia emissions.

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