APPLICATION OF SUITABILITY INDEX TO TURKISH COASTS FOR WAVE ENERGY SITE SELECTION

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MEHMET ERKAM BOZGEYIK

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submitted by **MEHMET ERKAM BOZGEYIK** in partial fulfillment of the requirements for the degree of **Master of Science in Civil Engineering Department, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences** __________________

Prof. Dr. Ahmet Türer
Head of Department, **Civil Engineering** __________________

Assist. Prof. Dr. Gülizar Özyurt Tarakcıoglu
Supervisor, **Civil Engineering, METU** __________________

Assist. Prof. Dr. Cüneyt Baykal
Co-Supervisor, **Civil Engineering, METU** __________________

Examining Committee Members:

Prof. Dr. Ahmet Cevdet Yalçıner
Civil Engineering, METU __________________

Assist. Prof. Dr. Gülizar Özyurt Tarakcıoglu
Civil Engineering, METU __________________

Assist. Prof. Dr. Cüneyt Baykal
Civil Engineering, METU __________________

Prof. Dr. Bülent Akınoğlu
Physics, METU __________________

Assoc. Prof. Dr. Yakup Darama
Civil Engineering, Atilim University __________________

Date: 12.09.2019

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Surname: Mehmet Erkam Bozgeyik

Signature:

ABSTRACT

APPLICATION OF SUITABILITY INDEX TO TURKISH COASTS FOR WAVE ENERGY SITE SELECTION

Bozgeyik, Mehmet Erkam
Master of Science, Civil Engineering
Supervisor: Assist. Prof. Dr. Gülizar Özyurt Tarakcıoglu
Co-Supervisor: Assist. Prof. Dr. Cüneyt Baykal

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Recently, renewable energy resources are getting more important day by day since energy demand of the world is continuously increasing. One of the promised renewable energy sources is wave energy as the water covers more than 70% of the world. Moreover, Turkey has potential to exploit from wave energy as it is surrounded with seas and Turkey has been searching for proper solutions in order to satisfy energy demands from past to now. In this regard, there are many studies executed in the literature for the evaluation of wave energy potential of Turkish seas, however, there are relatively less studies which discuss the site selection of Wave Energy Converters (WECs) by considering the factors from different fields. Therefore in this study evaluation of site selection for WECs around Turkish coastlines are performed by focusing on selection of the parameters affecting the site selection and integration of these parameters. Both the parameters and their relations between them should be analyzed as a whole. Moreover, parameters involved in a site selection study usually have a various importance degree and these can change according to the priorities of the region. Therefore, there is a need to develop a decision making model, which considers other local factors besides wave energy potential, in a Geographical Information System (GIS) in order to increase the accuracy of the results. After defining the factors from different fields namely; technical, environmental and socio-economical parameters, their interrelationship between each other were investigated by considering different perceptions of the researchers. Finally, suitability index, a Multi Criteria Decision Making (MCDM) technique was applied to these parameters in GIS environment. The suitability index was applied for equal weighting of parameters and weights assigned considering the literature. Additional index application was performed using different wave energy datasets to show the sensitivity of suitability index to input variation. The results show that western Black Sea coasts of Turkey is the most suitable site for WECs considering a variety of parameters. Although the quantitative results of suitability index is sensitive to the weighting and input data, areas determined as the highest and lowest suitable classes are consistent.

Keywords: Suitability Index, Site Selection, Wave Energy, Turkish Coasts

ÖZ

DALGA ENERJİSİNE YER SEÇİMİ İÇİN TÜRKİYE KIYILARINA UYGUNLUK İNDEKSİ ATANMASI

Bozgeyik, Mehmet Erkam
Yüksek Lisans, İnşaat Mühendisliği
Tez Danışmanı: Dr. Öğr. Üyesi Gülizar Özyurt Tarakcıoglu
Ortak Tez Danışmanı: Dr. Öğr. Üyesi Cüneyt Baykal

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Günümüzde dünyanın enerji ihtiyacının artması sebebiyle yenilenebilir enerji kaynaklarının önemi her geçen gün artmaktadır. Dünyanın %70 inden fazlası sular ile kaplandığı düşünüldüğünde dalga enerjisi gelecek vaat eden yenilenebilir enerji kaynaklarından birisidir. Dahası, Türkiye 3 denizle çevrilidir ve geçmişten günümüze enerji taleplerini karşılamak için sürekli olarak uygun çözümler aramaktadır. Bu bağlamda, literatürde Türk denizlerinin dalga enerjisi potansiyelinin değerlendirilmesi için yapılan pek çok çalışma vardır, ancak, Dalga Enerjisi Dönüştürücülerinin (WEC'ler) yer seçimini farklı alanlardaki faktörleri dikkate alarak tartışan nispeten daha az çalışma vardır. Bu çalışmada Türkiye kıyılarında dalga enerji konvertörlerinin uygunluk indeksi yönemi kullanılarak yer seçimi amaçlanmışdır. Dalga enerji konvertörleri için saha seçiminin değerlendirilmesi için yer seçimini etkileyen parametrelerin belirlenmesi ve“bu parametrelerin uygun şekilde entegre edilmesi gerekmektedir. Hem parametreler hem de aralarındaki ilişkiler bir bütün olarak analiz edilmelidir. Ayrıca, yer seçimi çalışmasında yer alan faktörler genellikle çeşitli önem derecelerine sahiptir ve bölgenin önceliklerine göre değişebilirler. Bu nedenle, sonuçların doğruluğunu arttırmak için Coğrafi Bilgi Sisteminde (CBS) dalga enerjisi potansiyeli dışında diğer yerel faktörleri göz önünde bulunduran uyguluk indeksi modeli kullanılmasına karar verilmiştir. Farklı alanlardaki parametreleri tanımladıktan sonra (teknik, çevresel ve sosyoekonomik parametreler), parametrelerin birbirileri olan etkileşimi iki farklı açıdan değerlendirilmişti. Uygunluk indeksi parametrelere hem eşit ağırlık tanınarak hem de literatürdeki kullanılan farklı ağırlık tanımları ile kullanılmıştır. Ayrıca uygunluk indeksinin farklı girdi veri setlerine olan hassaslığı en çok ağırlığa sahip dalga enerjisi potansiyeli parametresi özelinde değerlendirilmiştir. Sonuçlar Batı Karadeniz kıyılarının dalga enerjisi uygulamaları için en uygun yer olduğunu göstermektedir. Ayrıca uygunluk indeksi farklı uygulamalarda farklı sayısal sonuçlar vermekle beraber, özellikle en yüksek ve en düşük uygunluk seviyelerinin atandığı bölgelerin belirlenmesi açısından oldukça tutarlı sonuçlar ortaya koymaktadır. .

Anahtar Kelimeler: Uygunluk İndeksi, Dalga Enerjisi, Saha Seçimi, Türkiye Denizleri

To my esteemed family

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LIST OF ABBREVIATIONS

WECs	Wave Energy Converters
GIS	Geographical Information System
MCDM	Multi Criteria Decision Making
IEA	International Energy Agency
TWh	Terawatt-hours
AHP	Analytical Hierarchy Process
MPA	Marine Protected Areas

CHAPTER 1

INTRODUCTION

Renewable energy sources are in increasing demand in all over world due to growing population of the world. Currently, a great number of renewable energy projects has been carried out in many countries as well as many of them are under construction. When it is thought on the issue that the traditional energy production methods are causing to several environmental problems, exploitation from the renewable energy sources are gaining much more importance. They are expected to be a integral component of the future energy supply systems. Moreover, a major part of the renewable energy sources are more pollution-free, indigenous and sustainable compared with the conventional energy production methods.

One of the promoted renewable energy sources is wave energy for the sake of energy procurement. BWEA (2006) (as cited in Prest et al 2007) stated that, The British Wind Energy Association (BWEA) is claming that the global potential wave energy amount has been calculated around 1 to 10 Terawatts (TWs). Panicker (1976) (as cited in Zubiate et al 2005) mentioned that when the technology of wave energy devices is developed adequately, 10% of the world energy need can be fulfilled by wave energy according to the literature estimates. Although, wave energy converter technology is relatively new and unused comparing with the other sources such as solar and wind energy, interest of the sector authorities is gradually increasing.

Turkey is a growing market which continuously strives for the best energy solution. Also Turkey’s geographical location could be an advantage in terms of exploitation from wave energy. In this perspective, wave energy may encounter some of the energy expectancy of Turkey in the near future.

Energy existency has certainly a major importance influencing the wave energy plantation, however, in order to avoid and reduce conflicting with other marine users, all the necessary features that affect the site selection of wave energy converters (WECs), have to be involved and analyzed together. Indeed, it is clearly obvious that when selecting a location for wave energy farms, energy potential is not the only parameter to taken into consideration, proper selections require a compherensive spatial planning. Besides the wave energy potential, social, ecological and technical parameters should be elaborated rigorously. In this regard, idenfiying an appropriate location for the deployment of wave energy devices can be specifically called as a geo-spatial phenomena.

Furthermore, in the earlier stage of the energy planning design process, geo-spatial muti-criteria analysis is a convenient technique to take into account, numerical results of the parameters from the numerous fields are compared between each other for the given scale. As achieving a consensus between the operating sectors in the marine region, decision makers have to be conducted a comprehensive study for the identification of the eligible areas of wave energy farms. Hence, assigning a suitability index for each location have an enormous importance for the decision making process in order to determine appropriateness of the location. Besides that a comprehensive study for the site selection of WECs prevent the interference with the other marine uses which iş also another important aspect in terms of social acceptability for WECs. As Galparsoro et al (2012) stated that in order to receive preferable spatial planning results for the marine environment, the developed suitability model consists of environmental, technical and socioeconomical constraints, in an integrative way.

For the purpose of the addressed problem, using of Geographical Information System (GIS) is the necessarily step to be taken for the visualization, integration and analization by considering qualitative and quantitative parameters (Jankowski 1995).The feature of visualization employed by GIS provides users to obtain a better comprehension of patterns and trends which are defined in the dataset (Le et al. 2016). The analysis capability offered by a GIS software provides easily accessible spatial data which can be usable for the decision making mechanism in the marine region by analyzing multiple objectives (Le et al. 2016).

Consequently, through combining GIS and Multi Criteria Decision Making (MCDM) techniques, decision makers used to have better equipped for both optimizing ambiguous problems as well as conducting management techniques for the marine spatial planning. Thus Integration of GIS and MCDM for the plantation of wave energy farms plays an important role, since the accommodation of WECs requires the consideration of multi-diciplinary study, involving technical, economical, environmental aspects.

However, there are limited study in the literature that consider multiple parameters for the procurement of wave energy on Turkey's coastal. Therefore, this study is developed to assess the suitable sites for WECs on the coastal areas of Turkey by combination with multiple parameters recognized by experts and researchers in the literature using the method of suitability index.

In chapter two, answers of the following questions are briefly explained through comprehensive literature review;

- why wave energy is important and how it is calculated,
- which parameters have to be considered besides wave energy potential,
- what is aggregation of MCDM and GIS and how useful it is in site selection of WECs.

In the chapter three, the method used in this study is described briefly which cover the internal benchmarking of parameters as well as relationship between each parameter are mentioned. Besides that the mathematical model investigated in this study is also elaborated in this chapter. In the chapter four, results of the analysis showing the best suitable regions are presented under different scenarious. Consequently, conclusions, shortcomings and further remarks are mentioned in the chapter five.

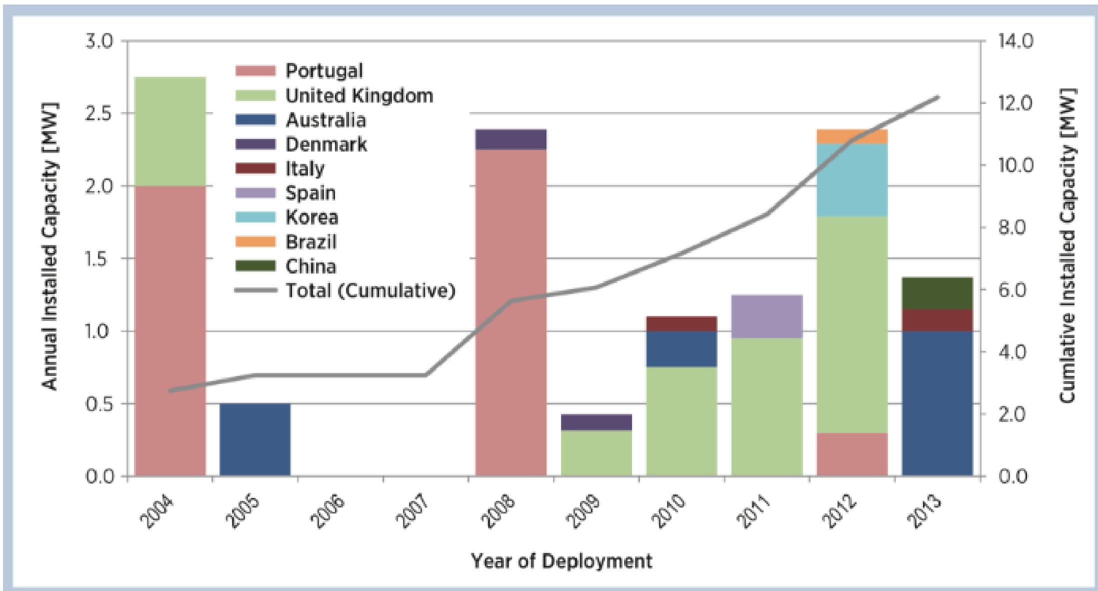
CHAPTER 2

LITERATURE REVIEW

2.1. General Information on Wave Energy

Since ancient civilisations the ocean has been important constituent of human life. Although generating electricity from ocean power has been studying from 18 century, technology can be exploitable from this abundant source has been produced recently (Renewable and Agency 2014). According to International Energy Agency (IEA, 2013), ocean energy is one of the most abundant resource with theoretically having 20 000 TWh to 80000 TWh of electiricity for each year which is almost enough to satisfy 100 and 400% of the world energy demand. In this regard, in order to recognize this vast resource many attempts are promoted globally to exploit and generate a new market for ocean energy. As an example, IEA-Ocean Energy Systems Implementing Agreement includes that global target of exploitation from ocean energy by 2050 is installing 337 GW systems (IEA 2013).

Mørk et al (2010) mentioned that researchers have been studying on wave energy since 1970s and first application of wave energy converters launched in the mid 1980s with scaled prototypes and they were tested in the sea. They consider that wave energy technology is not completely commercially, it is still in pre-commercial stage and determination of wave energy potential issue is also under construction and lots of work is progressing on this promised renewable energy resource.



Based on analysis of data from DNV GL (2014)

Note: Includes any new, large-scale (i.e., greater than 100 kW) deployment as of February 2014, regardless of grid-connection and time deployed (although most large-scale prototypes were grid connected). As some units were removed after testing periods or failed during the trial effort, cumulative capacity deployed does not represent total installed capacity today.

Figure 2.1. Summary for the deployment of wave energy prototype (Renewable and Agency 2014).

As it is seen from the Figure 2.1 until 2014 all the deployments are in pre-commercial phase all around the world. Figure 2.1 illustrate the geographic distribution of prototype wave energy conversion devices and we can say that Portugal and UK are the main hub locations where most of the activities have been executed (Renewable and Agency 2014).

There are many tecnological devices provided in the literature for harnessing from wave energy. The most used ones, which are also in the field of interest of this study, are described in the below figure.

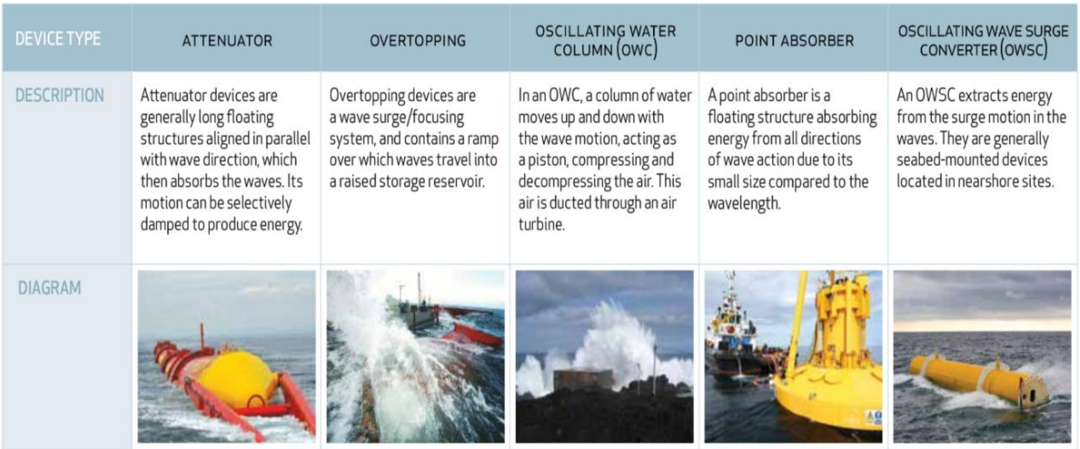


Figure 2.2. Type of wave energy converters and features (Magagna and Uihlein 2015a).

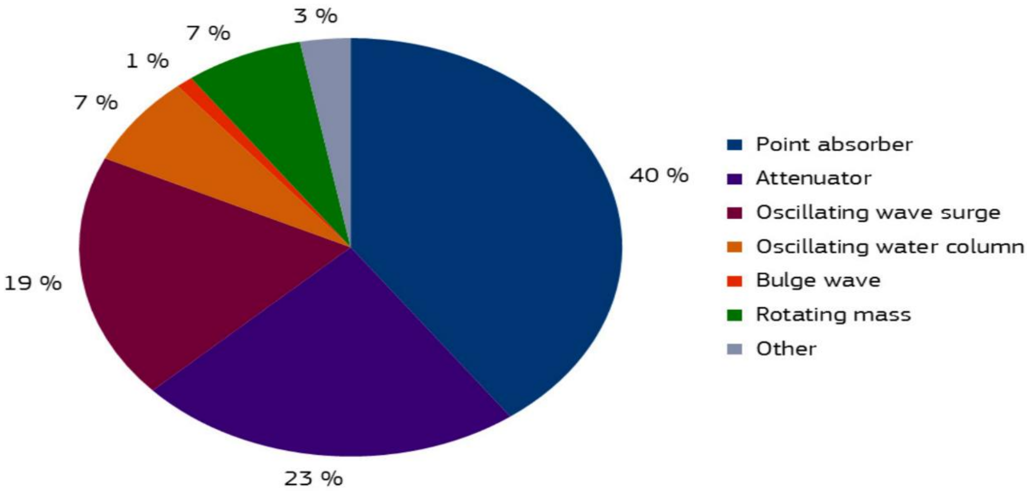


Figure 2.3. Pie charts of R&D activities related to WEC type (Magagna and Uihlein 2015a).

According to Figure2.2 and Figure 2.3, the devices which are related with most of the research efforts, are generally transform the kinetic and potential energy to another. This transformation is directly related with the wave height and wave characteristics, therefore, the regions with high wave height which means high wave energy flux

(Kw/m), are tend to be better wave resources (Huckerby, J., Jeffrey, H., Sedgwick, J., Jay, B. and Finlay 2012).

Wave Energy Converters (WECs) basically convert the kinetic and potential energy of surface of the ocean into further energy form like electricity. "These waves, generated primarily by wind blowing across the ocean surface (ripples), can propagate over deep water with minimal energy loss and will combine and continue to gain energy from the wind over long open ocean stretches (leading to swells). Although the air-sea interactions and energy transfer mechanisms are complex, ocean surface wave formation is primarily influenced by the speed of the wind, its duration and the fetch (distance of open water over which the wind blows)" (Renewable and Agency 2014).

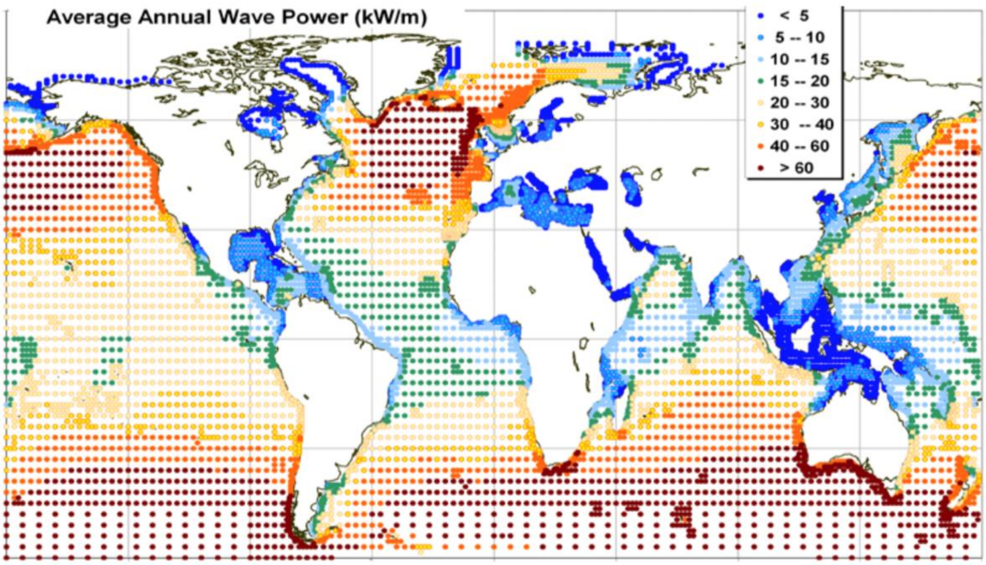


Figure 2.4. Global annual average wave power distribution in kW/m (K. Nielsen 2010).

Consequently, wave energy one of the abundant renewable energy resource as shown in the Figure 2.4 and it is not only generating electricity also it has many advantages as outline below;

- Protects natural balance

- Clean air
- Encourage national economy policy
- Reduce the need for fossil fuels
- Generate clean and indigenous energy
- Low variable comparing with the other sources

2.1.1. Calculations of Wave Power

There are many different techniques and models in order to get acquisitions from the ocean waves. Information of the wave climate have an significant importance for the design and feasibility studies of the wave power. Since the wave energy generation has possessed a priority in the world, an elaborated wave climate analysis is necessary in order to get esteemed informations about on wave power. Field measurements with wave gauges are the best way for getting an information on a wave resource for a location. However, determination of wave climate for the entire region with these limited amount of gauges, is not possible. Instead of getting in-situ measurements for the entire region, spectral wave models (WAM, MIKE 21 SW, WAVEWATCH III, SWAN) have made enourmous advancements in the knowledge of wave mechanics.

Gulev (2003) stated that in the past most of the wave climate researches were carried out by voluntary investigation ship data. However these data were limited sampling intensity especially during the extreme weather conditions. Zacharioudaki et al (2015) (as cited in WASA Group 1998) mentioned that until 1990s, the development in the numerical models increased the computational rate of these studies. Currently, numeric models are the most proper way for the determination of wave climate since it provide homogeneous long-term results with uninterrupted datasets. Also, In situ measurements and satellite records are generally used to approve the accuracy of the numeric models but usually they are not employed on their own due to poor spatial recordings (Zacharioudaki et al. 2015).

According to Akpınar et al (2017) wave power can be determined from the output of numerical wave model as formulated below;

$$Pw = \rho g \int_0^{2\pi} \int_{f_{lower}}^{f_{upper}} S(f,\theta)\, c_g(f,d)\, df\, d\theta \tag{2.1}$$

where $S(f,\theta)$ is the directional wave density spectrum, c_g is the group velocity, d is water depth, f is the wave frequency, θ is the direction of propagation of the spectral component, ρ is the water density, g is the gravitational acceleration.

After having considered the analysis in deep water conditions (d / L > 0.5, where L is the wavelength), the expression turn into:

$$Pw = \frac{\rho g^2}{64\pi} \times {H_{m0}}^2 \times T_e \tag{2.2}$$

where H_{m0} is the spectral wave height obtained from the spectrum, which is calculated as:

$$H_{m0} = 4\sqrt{\mathrm{m0}} \tag{2.3}$$

And also in the literature T_e is the energy period which is known as:

$$T_e = \frac{m_{-1}}{m_0} \tag{2.4}$$

where m−1 and m0 are spectral moments based on the nth order spectral moment

$$m_n = \int_0^{2\pi} \int_{f_{lower}}^{f_{upper}} f^n\, S(f,\theta)\, df\, d\theta \tag{2.5}$$

The total annual wave energy which is generated during a given time interval (Δt) is calculated as below:

$$E_{total} = \sum_i P_i \times \Delta t_i \tag{2.6}$$

where Δt_i is the temporal sampling interval.

2.2. Identification of Other Parameters for the Site Selection

Earlier the studies generally has focused on efficiency and cost issues for the energy production planning (Galparsoro et al. 2012). However Spaulding et al. (2010) states that (as cited in Galparsoro et al. 2012) , recently, the necessity for the consideration of social and environmental aspects along with technical issues has been approved. In order to identify most adequate regions for the deployment of wave energy converters, the conflicting parameters and other uses in the marine areas are gaining importance to increase the accuracy of the spatial analysis for the site selection of wave energy farms. In the literature these aforementioned parameters generally gathering around the three major factors. These factors as sorted below in conjuction with the associated sub factors:

1. Technical Factors
   - Wave power,
   - Depth range,
   - Distance to ports,
   - Electrical grid
2. Environmental Factors
   - Marine Protected Areas,
   - Military Exercise Areas,
   - Fishing Activities
   - Ship Wrecks.
3. Socio-economic Factors
   - Tourism Potential,
   - Shipping Density
   - Population Served.

Nobre et al (2009) performed a study to choose proper location for WECs. Their analysis describe the non-implementing regions as below;

- Military Exercise Areas
- Marine Protected Areas
- Wave Shadow Areas
- The areas that out of the water depth range of 30 m to 200 m.
- Harbour entrances.

While the factors considered as weighted were:

- Distance to coastline
- Distance to ports
- Distance to the electrical grid
- Wave climatology
- Type of Sea Bottom

Galparsoro et al (2012) identified 17 parameters for the installation of wave energy conversion systems and grouped them under three main headings which are technical factors, environmental factors and socioeconomic factors. As examples of technical considerations for their study are wave energy flux, depth range, distance to harbours, seafloor typology. While environmental and socioeconomic factor consist of protected natural site, special protected areas for wild birds and fisheries, bathing zones, respectively.

The below figures as an example of site selection parameters for the Hybrid Offshore Wind and Wave Energy Systems in the study of “GIS-based multi-criteria decision analysis for site selection of hybrid offshore wind and wave energy systems in Greece” carried out by Vasileiou et al (2017).

Category	Exclusion Criteria		Unsuitable areas
	No.	Description	
Utilization restrictions	EC1	Military Exercise Areas (MEA)	All
	EC2	Areas to be licensed for Exploration and Exploitation of Hydrocarbons (AEEH)	All
	EC3	Areas where Offshore Renewable Energy Projects are planned to be or have been installed (AOREP)	All
	EC4	Marine Protected Areas (MPA)	All
Economic and technical constraints	EC5	Wind Velocity (WV)	< 6 m/s
	EC6	Wave Energy Potential (WEP)	< 5 kW/m
	EC7	Water Depth (WD)	> 500 m
Social constraints	EC8	Distance from Shore (DS)	< 25 km

Figure 2.5. Exclusion factors for the plantation of Hybrid Offshore Wind and Wave Energy Systems (Vasileiou et al. 2017b).

Evaluation Criteria		Factor
No.	Description	
C1	Wind Velocity (WV)	Economic/Technical
C2	Wave Energy Potential (WEP)	Economic/Technical
C3	Water Depth (WD)	Economic
C4	Distance from Shore (DS)	Economic
C5	Connection to Local Electrical Grid (CLEG)	Economic/Technical
C6	Population Served (PS)	Economic/Socio-political
C7	Shipping Density (SD)	Socio-political
C8	Distance from Ports (DP)	Economic

Figure 2.6. Evalutaion factors for the plantation of Hybrid Offshore Wind and Wave Energy Systems (Vasileiou et al. 2017b).

2.2.1. Technical Factors

2.2.1.1. Wave Energy Potential

As might be expected, the amount of the power resource is the most vital parameter that should be taken into consideration in the assessment (Zubiate et al. 2005). It is the most utilized technical parameter in order to assess renewable energy plants. Some regions are not productive indigenously for exploiting from the wave energy. In contrast, some of the regions are more efficient due to long fetch distance and frequency of the wave group. Therefore, many researchers considered this parameter relatively more important than other parameters so that they gave the highest weighting factor comparing the other parameters.

Le et al (2016) conducted a study to choose convenient regions for WECs in Australia using Analytical Hierarchy Process (AHP) which is a well-known MCDM technique. Their study considered wave power as most important parameter in the analysis as evaluation rankings of the criteria shown in Figure 2.7.

Criteria	*Weight*	*Rank*
Shipping	0.0230	6
Fishing	0.0226	7
Aquaculture	0.0239	5
Cables	0.0220	8
Oil fields	0.0166	9
MPAs	0.0776	3
Marine Lease	0.0144	10
Wave power	0.5257	1
Benthic terrain	0.0567	4
Water depth	0.2176	2

Figure 2.7. AHP ranking scores of the factors (Le et al. 2016).

Similarly, Vasileiou et al (2017b) studied site selection for the combination of wind and wave hybrid systems using AHP. Their investigation considered wave parameter relatively more important to other parameters as well. According to their evaluation, ranking of the selected parameters as shown in Figure 2.8.

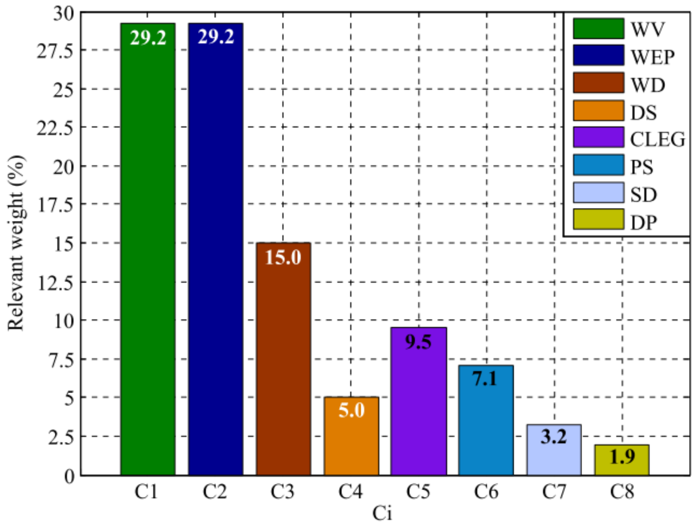


Figure 2.8. Weight comparison of the parameters in the study of Vasileiou et al (2017b). (WV: Wind Velocity, WEP: Wave Energy Potential, WD: Water Depth, DS: Distance from Shore, CLEG: Connection to Local Electrical Grid, PS: Population Served, SD: Shipping Density, DP: Distance from Ports)

2.2.1.2. Depth of the Sea

In any case of ocean either the location for wave energy conversion have high energy or not, depth of the ocean should be appropriate for the installation of converters. Most of the conversion systems are employable for the depth range of 30 m to 200 m (Nobre et al. 2009).

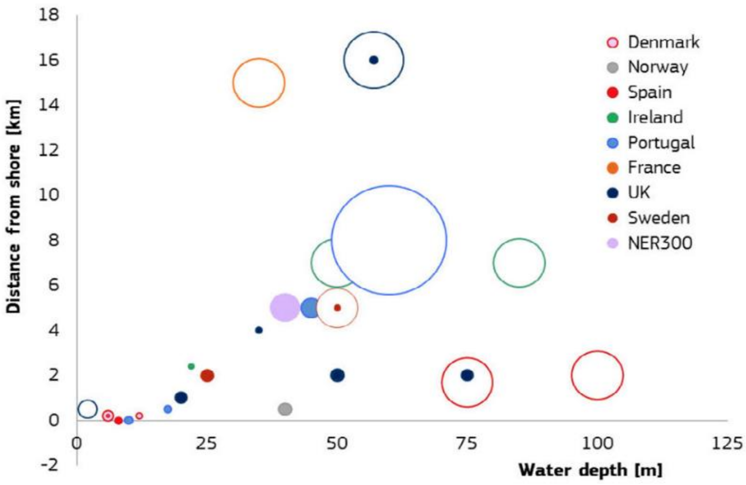


Figure 2.9. Installed wave energy devices in Europe. The bubble size indicates the capacity of the project (Magagna and Uihlein 2015b).

Magagna and Uihlein (2015) mentioned that even though most of the installations carried out within 10 km distance from shore as shown in Figure 2.9, major part of the wave energy devices are developed for offshore implementation. However, it is obvious in Figure 2.9 that high capacity installations have been executed within the water depth of 50 m and 100 m water depth. Therefore we can deduce that areas between 50 m and 100 m are more preferable for the installation of wave energy converters.

2.2.1.3. Proximity to Ports

Flocard et al (2016) mentioned that the success of the wave energy project directly connected with the accessibility of the infrastructure during the construction stage as well as after commissioning the project. They also added that considering the life of the project, the necessity of vessel facilities may be categorized two parts based on current industry knowledge. The planting of WEC devices most probably requires large vessels which reveals the requirement of deep draft around 10 m to 15 m meaning that relatively large harbours are needed during the construction stage of wave energy farm. In contrast, after start-up the project, the proximity to smaller ports enrich the economic survivability of the project in order to encourage operation and maintenance.

Zubiate et al (2005) stated that construction of the wave energy farms as well as serviceability of the facilities require a sufficient harbour. In this regard, they have also mentioned that installation of cables which is an another vulnerable process; besides, routine maintenance activities should also involve a nearby harbour.

According to Vasileiou et al (2017a), the closer it became to a port, the more they saw it preferable one, since the vicinity a port decrease the construction costs. Because of this reason, they have listed under five categories in order to show preference order as shown below:

- 50-60 km to a port (Extreme importance)
- 60-70 km to a port (Very strong preference)
- 70-80 km to a port (Strong preference)
- 80-90 km to a port (Weak preference)
- 90-100 km to a port (Less preference)

2.2.1.4. The Electricity Network

Since the greater distance from the electrical grid location will raise the investment cost, proximity to existing connection network is a good reason for preference as it decreases cabling costs (Flocard et al. 2016).

Zubiate et al (2005) mentioned that a wave energy production site ultimately aims to transport and convey the generated power. Even if these facilities installed just for testing and showing advances, still, the availability of grid locations within the region would be fundemantal. Their study also stated that technical details of the grid locations such as voltage and infusion capacity has also enourmous importance which is in good agreement with the consumption of the regions. Population density of these regions are usually high which give an important clue for the availability of strong grid.

Cradden et al (2016) described a systematic framework for selecting locations of renewable energy platforms in order to improve efficiency of combined renewable energy systems. In the study electricity network considered as a predictive factor of investment costs. For this reason, beyond 150 km from the shore left it out of scope for this study as cabling costs rising significantly.

Vasileiou et al (2017b) utilized the vicinity to a available high voltage capacity of electrical gird location to satisfy project success from the marginal viewpoint. They have defined four network capacity with the increasing order of preference;

- 66 kV,
- 150 kV,
- 220 kV,
- 220-400 kV.

2.2.2. Environmental Factors

2.2.2.1. Marine Protected Areas (MPA)

Some areas of the ocean have specific environmental importance which may be an obstacle and interfere with the installation of energy devices (Cradden et al. 2016). In these regard, awareness of these areas are significant contributor for the success of the project.

Vasileiou et al 2017b; Galparsoro et al 2012; Nobre et al 2009; Zubiate et al 2005; Flocard et al 2016; Papadopoulos and Synolakis, 2013; Aydin et al 2013 and many other researchers have considered MPA as a exclusion criteria for the proper accommodation of wave energy converter devices. In their studies, MPA identified as natural values of a country which the viability of the areas are protected with national legislations. Therefore, in the papers, MPA are directly excluded from the study framework.

2.2.2.2. Military Exercise Areas

These regions are not suitable for siting renewable energy devices, since they are used for the application of military actions. Therefore, these no go regions are also excluded in the literature. However, when all the conditions are mature, negotiations with governments may be possible since government policies are interchangeable.

2.2.2.3. Fishing Activities

It is obvious that fisheries is an important commercial activities that is taken to consideration. This is sometime not just the commercial activities but also a cultural heritage. In this regard, many of the offshore powerplant researches consist of fisheries as a limiting factor.

Galparsoro et al (2012) conducted a study for the installation of WECs on the Basque Continental Shelf and they have given a limiting value for some of the fishing regions since the fishing activites relatively intense in these areas.

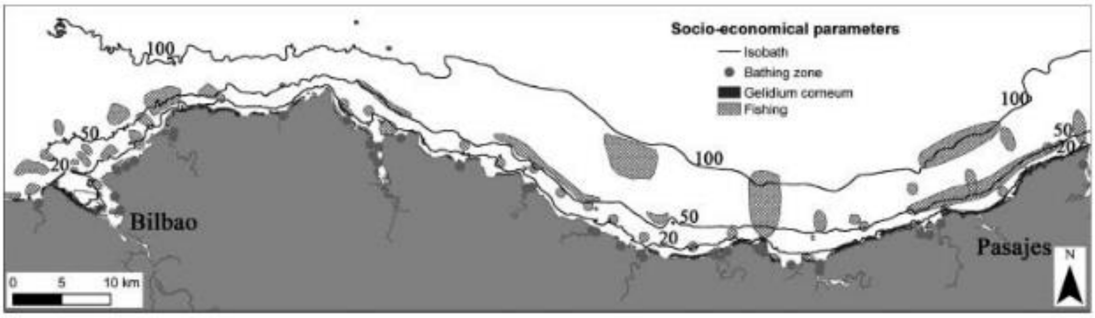


Figure 2.10. Map showing the fishing activities considered in the suitability index calculation .(Galparsoro et al 2012).

Flocard et al (2016) have also eliminated the locations where the fishing activities are more densely populated.

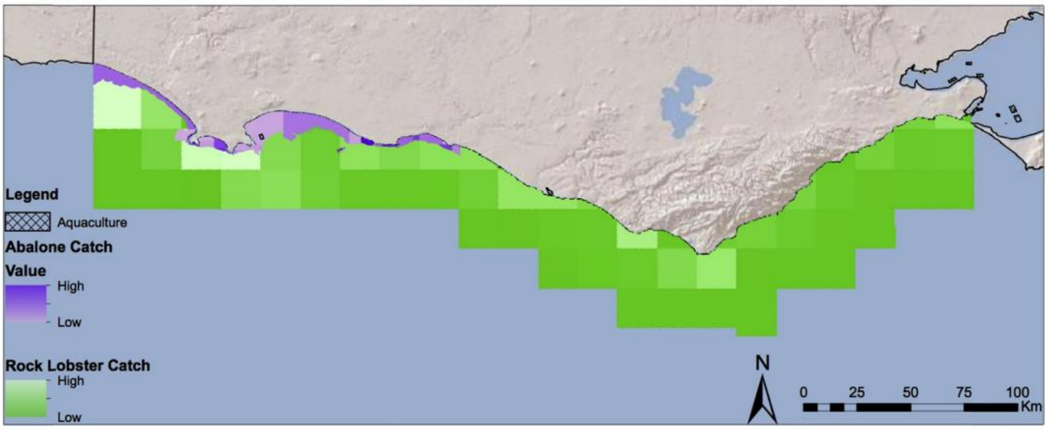


Figure 2.11. Elimination of fishing areas in the study of Flocard et al (2016).

2.2.2.4. Submarine Archaelogy

Even though the ship wrecks may not be available in every coast, but the locations including an archaeologic value would be absolutely considered as a excluding factor since they have a significant historical importance (Zubiate et al. 2005).

2.2.3. Socio-Economic Factor

2.2.3.1. Tourism Potential

Identifying the possible pros and cons in terms of social reactions associated with the expected development in wave energy is crucil in order to provide a social acceptance for the developing renewable energy investment (Papadopoulos and Synolakis 2013).

Even though most of the beach activities are carrying out close to onshore, where currently unfeasible to deploy WECs because of broken waves, incompatibility with the wave energy should be taken into consideration for the specific conditions.

2.2.3.2. Shipping Density

The regions having high volume of shipping traffic is certainly seen as unfeasible locations for deploying offshore renewable energy platform (Cradden et al. 2016).

Vasileiou et al (2017b) mentioned that the installation of these powerplants should not interfere with primary shipping lane. This is so vital, especially for Greece where the social activities and territorial coherence strongly depend on un-coincident and safe navigation routes. Hence, in their study, marine areas with low density of shipping traffic were seen as the most intended places. Consequently, shipping density factor were separated three according to their preferability as low, medium and high. The associated evaluation executed with visual estimation of satellite data ensured by the European Marine Observartion and Data Network (EMODnet) (https://www.emodnet-humanactivities.eu/about.php).

2.2.3.3. Population Served

The population amount is also another aspect that should be taken into consideration regarding energy needs of the territory for providing economic sustainability and socio-political admissibility of the project. In this regard, Vasileiou et al (2017b) selected the most preferable area where its population is the largest one.

2.3. Multi Criteria Decision Making Combined with Geographical Information System (GIS)

2.3.1. Multi Criteria Decision Making

Voogd (1983) and Nijkamp (1980) stated (as cited from Carver 1991) that Multi Criteria Evaluation (MCE) methods arised, in the early of 1970s, from the discussion of conventional neoclassical economics and shortcomings of the zonal financial planning and decision making methods have defined by some workers. After that many alternative methods have been proposed to enhance the conventional methods which cannot deal with the external influences of the environmental and financial developments and it is clearly understood the necessity of more accurate planning process. Most of these proposed methods commonly focusing on the multi-dimensionality.

Multi-dimensional assessment models should encompass different disciplinal aspects such as environmental and economic effects for analyzing complex preference choices (e.g. regions, plans) (Carver 1991).

A decision making procedure starts with the identification of the problem which is perceived as the difference around the desired and existing status of the system. MCDM problems usually consist of five components which are: aim, preferences of decision maker, alternatives, required criterias and final outcomes (Kumar et al. 2017).

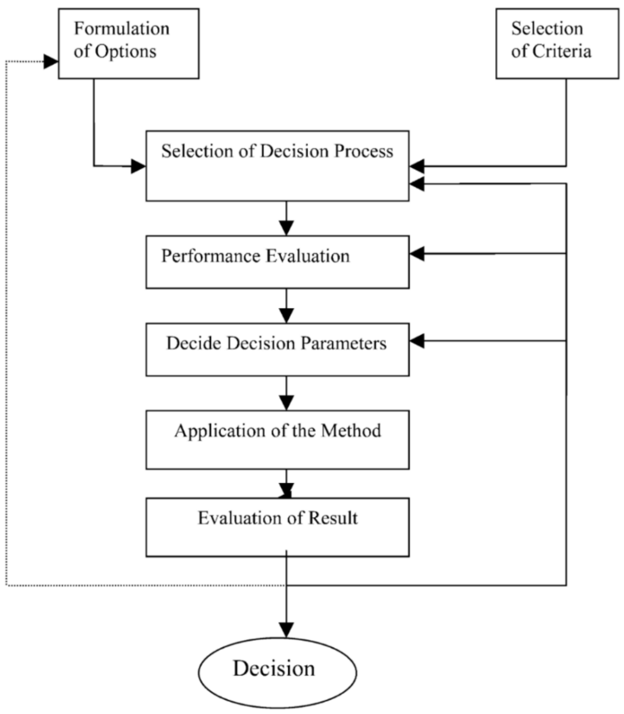


Figure 2.12. A general procedure for multicriteria decision problems (Pohekar and Ramachandran 2004).

There are numerous decision making methods described in the literature. These are listed as follows (Kumar et al. 2017);

- Weighted Sum Model (WSM) proposed by Fishburn in 1967.
- Weighted Product Method (WPM) proposed by Bridgman in 1922.
- The elimination and choice translating reality (ELECTRE) by Benayoun et al. in 1966.
- The technique for order preference by similarity to ideal solutions (TOPSIS) by Hwang and Yoon in 1981.
- Multi-attribute utility theory (MAUT) by Edwards and Newman in 1982.

Every model has unique and its own features and restrictions. According to Løken (2007) we cannot deduce that one method precede from others or in a similar way we cannot say that one method usually more compatible than others for the solution of the planning of energy problems.

Baban and Parry (2001) stated the most important problem encountered in the exploitation of renewable energy systems is the identification of the suitable sites. In order to meet these facing issues and to overcome complexity in the energy planning procedure, multi-criteria decision analysis methods have significant importance since they evaluate complex multi dimensional systems (Wang et al. 2009).

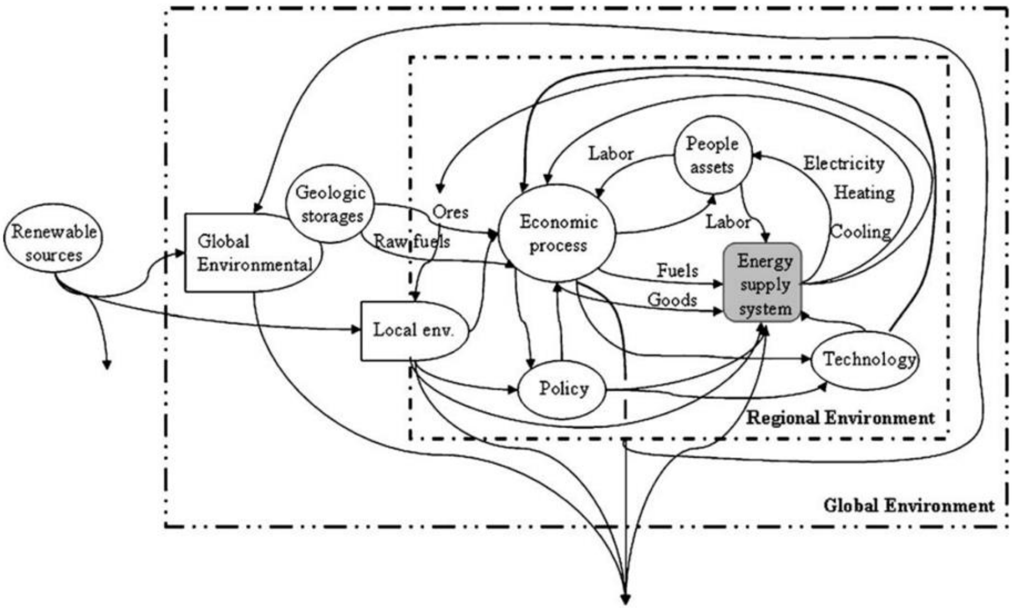


Figure 2.13. The complexity of decision making procedure in energy systems (Wang et al. 2009).

Le et al. (2016) conducted a study to optimal location for wave energy converters in Tasmania, Australia. Their study has combined two different MCDM techniques which are AHP and TOPSIS in order to cover the uncertanities of each other. Consequently they deduced that optimal locations for exploiting from wave energy may not always be in the areas where wave power is highest relatively.

Flocard et al (2016) has implemented Weighted Sum Model (WSM) for the recognition of the proper locations to install wave energy platform. Basicly, they weighted the selected parameters and determine the suitibiality index of locations. Additionally, their study included 7 additional cases by altering the weight of parameters in order to increase the robustness of the study.

2.3.2. Geographical Information System (GIS)

Geographic Information Systems (GISs) were advanced in the earlier 1950s, particularly in the public (Mark et al. 1997).

Malczewski (2004) mentioned that developments in GIS can be grouped in three time periods:

- 1950-1970 innovation time for GIS
- 1980s integration stage defining the main purpose of GIS systems
- 1990s development of participatory GIS technology.

Nowadays, Geographical Information Systems are using in the numerous fields and functionality in the geo-spatial decision making process is undoubtedly unique. Many researchers used GIS to determine proper locations for the renewable energy devices (Cradden et al. 2016; Flocard et al. 2016; Galparsoro et al. 2012; Le et al. 2016; Nobre et al. 2009; Vasileiou et al. 2017b). Since the selection and suitability of sites are associated with the geospatial process, hence facility of the GIS is non-negligible. Edward et al (2010) stated (as cited from Parry et al 2018) that a GIS suitability figure generally look for the answer of the question, "which location is more suitable for the project?". These means that the project should encompass the multiple parameters which are proposed by decision makers in order to solve with the aggreagation of Multi Criteriteria Evaluation and GIS.

2.3.3. Methodological Framework of Geographical Decision Making

Malczewski (2006) reviewed over 300 articles published between 1990 to 2004 on the subject that GIS based multicriteria decision analysis and he remarked the following briefly. Spatial decision problems usually consider multiple parameters which some of them conflict between each other while some of them feed each other. Decision makers usually evaluate these alternatives by involving lessons learned, stake holders and policy makers etc. Each parameters are usually weighted specifically according to their relative importance with respect to other parameters. In this regard, researchers found their solution by combining GIS and MCDM for many spatial decision problems. Like Laaribi et al (1996) mentioned that (as cited from Malczewski 2006), these two independent research areas, MCDM and GIS, may benefit from each other in many aspects. In other words, GIS plays an important role in order to analyze decision making problems. GIS is usually defined as a tool which supporting the decision making system by involving the datasets of referenced parameters. Moreover, MCDM encompasses many techniques and procedures for solving and evaluating decision making problems. Consequently, combining GIS and MCDM is a good way to visualize geographical data and judgments of decision maker in order to acquire proper consequences.

Hywood et al (2006) stated (as cited from Drobne and Lisec 2009) that GIS has been defined as a kind of decision supply system when dealing with the geo-spatial problems. Figure 2.14, perfectly describes the differences between conventional decision making and GIS-based spatial decision making.

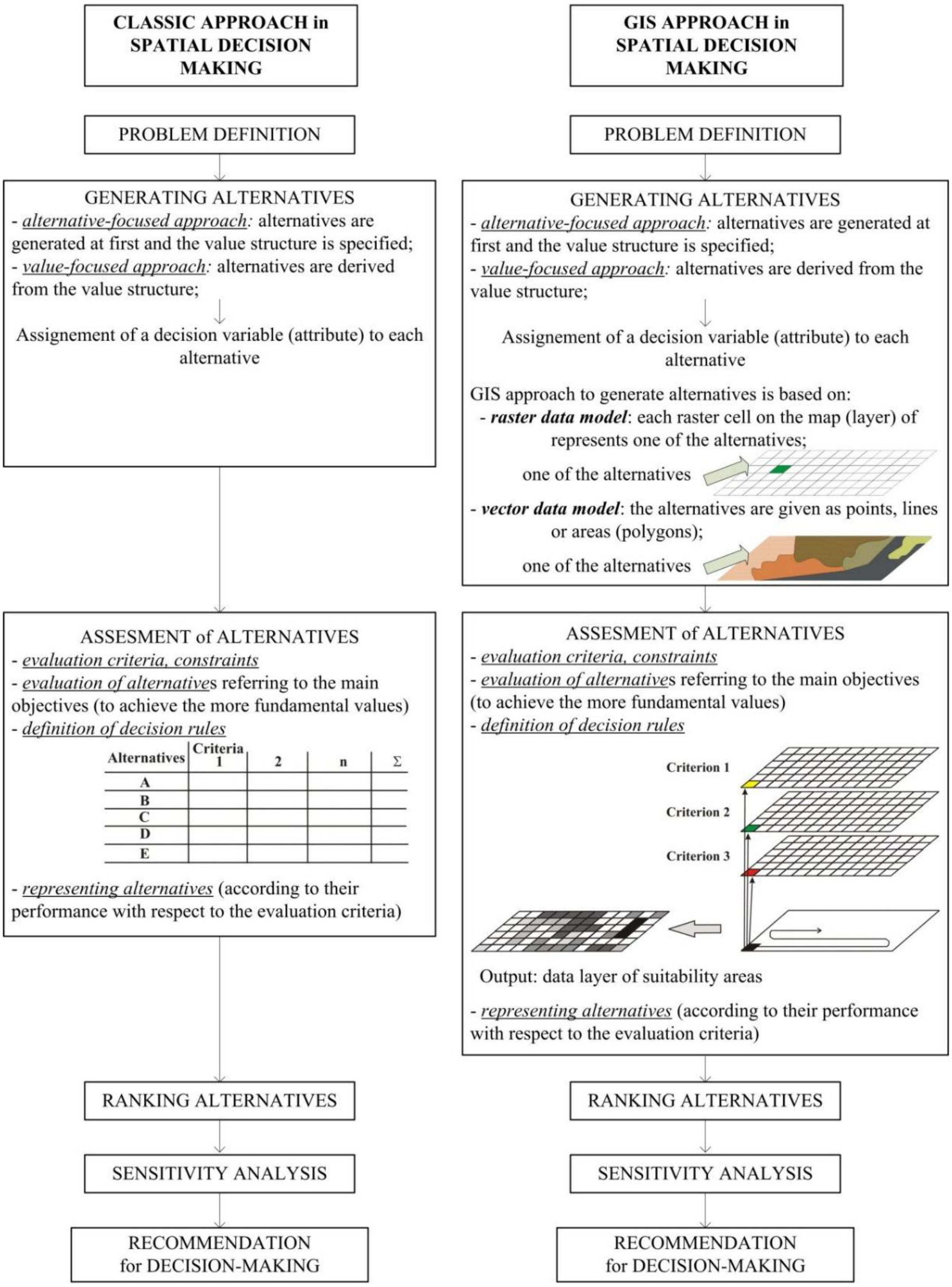


Figure 2.14. GIS-based and Classic geographical decision making process (Drobne and Lisec 2009).

CHAPTER 3

METHODOLOGY

In the literature there are many site selection studies for WEC systems. It is observed that comprehensive and diverse researches have been executed to identify proper parameters, and try to weight them by involving different stakeholders for wave energy farms. However, in Turkey, most of the wave energy studies are restricted considering only energy capability of the region, disregarding relationship between other factors which directly influence the acceptability of the study. These independent factors from each other and impacts of these factors in the suitable site selection should be taken into consideration as one body. Considering this point, a comprehensive framework covering the combined impacts for the site selection of WECs were developed in this study.

Mainly Black Sea, Mediterranean Sea and Aegean Sea was covered in this study. However, due to the following reasons, Aegean Sea was excluded from this study. First of all, because of the islands waves do not have long fetch distance which causes to energy loss in this region. Hence, the exploitable energy is relatively low comparing to Black Sea and Mediterranean Sea. Ayat (2013) and Vasileiou et al (2017b) studied wave power potential of Aegean Sea and results of their study presented in Figure 3.1 and Figure 3.2 ,respectively. Their results clearly show that wave energy in the border of Turkey's continental shelf zone is nominal in order to harness from them. Moreover, military activities, which is one of the exclusion criteria for this study as mentioned in the following sections, are covering wide range of area in Aegean Sea as it is seen from Figure 3.3. The last reason for the exclusion of Aegean Sea is the island dispute between Greece and Turkey. The exclusive economic zone and continental shelf zone of Turkey and Greece is still controversial which is also another complicated obstacle for the deployment of wave energy converters. Because of the abovementioned, Aegean Sea was extracted from the study region..

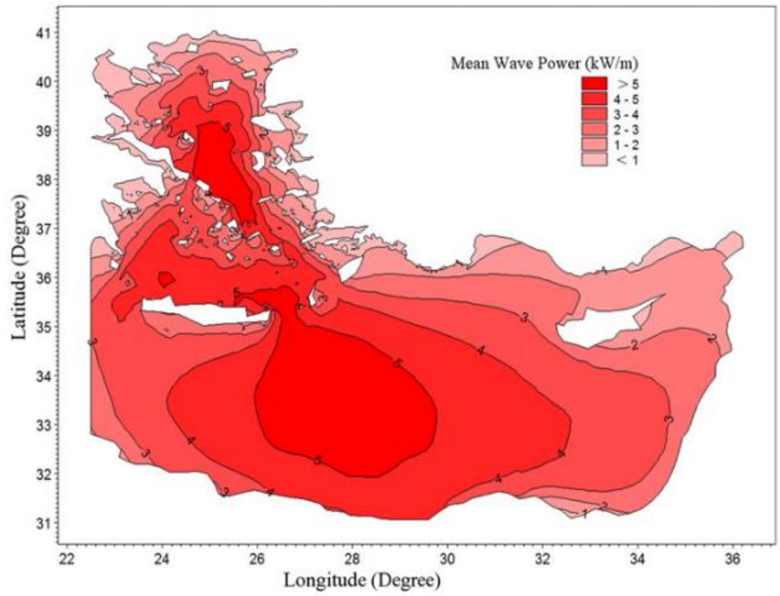


Figure 3.1. Mean wave power distribution (Ayat 2013)

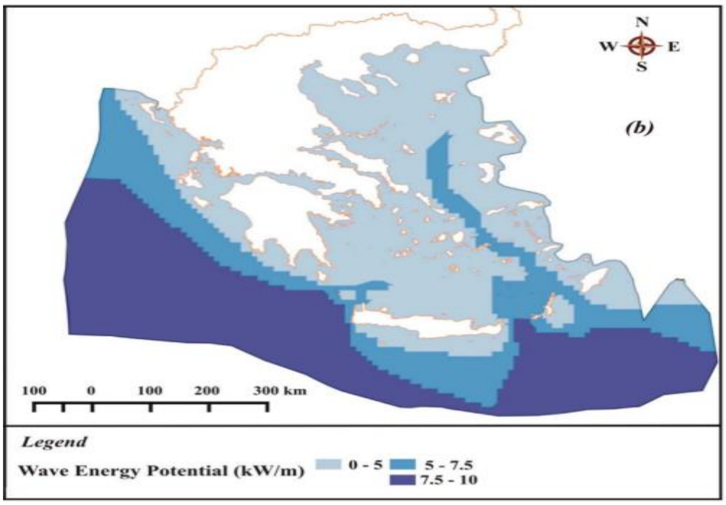


Figure 3.2. Wave power distribution of Aegean Sea from the perspective of Greeks (Vasileiou et al. 2017b).

Figure 3.3. Turkish military zones in Aegean Sea (www.shodb.gov.tr).

After determination of the study border, the factors affecting the suitability were chosen by considering technical, environmental, socio-economical issues. The investigation for the selection of parameters is not only carried out with the literature survey also paid attention to the specific features of the region. Therefore the offshore map were divided in GIS environment by 10km to 10 km grid cells (see Figure 3.4) and evaluation of each parameter has been executed in each gridded cell.

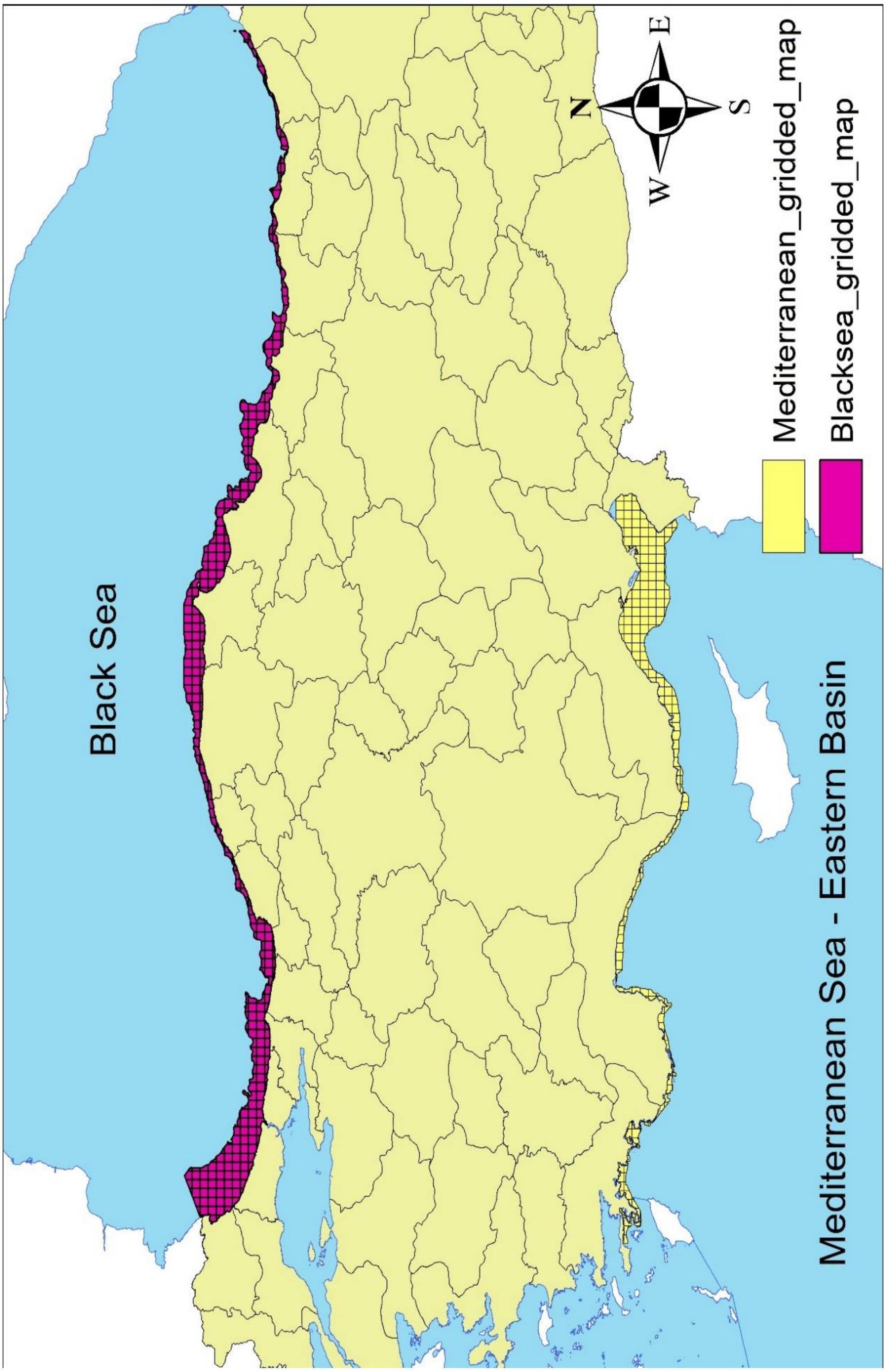


Figure 3.4. Gridded Map for Black Sea and Mediterranean Sea

Moreover, integrating and listing the parameters from different disciplines require a proper Multi-Criteria Decision Analysis (MCDA), therefore, Suitability Index method based on Weighted Sum Model (WSM) was found practical for this study which is described in a more detail in the following section. Throughout the literature, weighting the factors and assigning them a score according to their relative importance is a controversial and subjective issue. Thus, it is observed that taking the different researchers opinions is a vital process in the applicability of the project. Therefore, when assigning a weighting factor to each parameter comprehensive literature review has been executed. Besides that, the framework of the study was planned to consider that may work under different scenarios when scoring the parameters according to desired one.

Another remarkable issue through the literature survey is the aggregation of the study with a GIS software. For a very long time GIS has been using for site selection of renewable energy systems as mentioned in the previous chapter. In terms of visualization and analization of the study, GIS software were found very important and most of the multi-criteria decision analysis observations and environmental analyses were performed in ArcGIS 10.3.1.

Furthermore, this study includes two different discussions. The first one investigates the results of equal weighting and different weighting methods assigned to the parameters which mainly discuss comparison of the suitability index of the regions when these two case applied. The second discussion more concentrate to wave power of the regions presented in the articles. These two discussions were elaborated in a more detailed in the further sections.

3.1. Description of Suitability Analysis and İntegration with GIS

The primary goal of the most of the multi criteria decision analysis is to support the decision maker when choosing the best option from among the numerous feasible alternatives. There are many MCDM techniques mentioned in the literature such as

WSM, AHP, ELECTRE and TOPSIS. All of them have their own relative merits and it is not proper to generalize as one method better fit to solve major part of the decision analysis.

In this study, Suitability Index based on Weighted Sum Model (WSM) was used to rank the alternative regions. Formulation of suitability analysis can be typically shown as follows:

$$SI_{(x,y)} = \sum_{i=1}^{n} w_{i\,(x,y)} X_i \times \prod_{j=1}^{m} C_{j\,(x,y)} \qquad (3.1)$$

Where w_i is a weight created to factor i, X_i is a typical criterion score for factor i. However, various factors generally measured with different units and all of them have their own internal impact which constitute a necessity of a common scale in order to analyse them together. Therefore all the factors were converted in a normalized scale which basically ranging between "0" and "1". "1" describes the best value while "0" symbolized the least one. Besides the internal benchmarking of the parameters, relationship between each parameter is also investigated with the criterion score, X_i, given in the formula 3.1. This score is described more detailed in the following section, however, it basicly shows the relative importance of a parameter according to the other parameters.

Due to socio-economic or environmental reasons in some regions, installation of WECs is becoming impossible. Therefore, in order to consider also these factors, Boolean constraints, C_j, is also applied by multiplying the suitability determined from the factors. Values of C_j takes either "0" or "1" where "0" means unsuitable region and "1" describes suitable regions which means analysis can be properly progressed. "n" and "m" are the total number of used parameters and restrictive parameters, respectively.

In this study, suitability analyses were performed with the raster- based GIS which means some of the computations were executed outside of GIS. The main reason for creating partially integration analysis is that the approach for this study includes a many number of individual cell as it is seen from Figure 3.4. These individual cells represent the alternatives which are candidate for the potential region of WECs. More precisely, intensive computations for each cell in GIS environment is impractical, therefore, most part of the suitability analysis were carried out in Excel and the result of the decision analysis were merged with GIS for the spatial visualization.

Consequently, as Jankowski (1995) mentioned that aggregation of GIS and MCDA in a partially raster-based integration , is linked with three modules (Figure 3.5):

- GIS module
- MCDM module
- File converter module

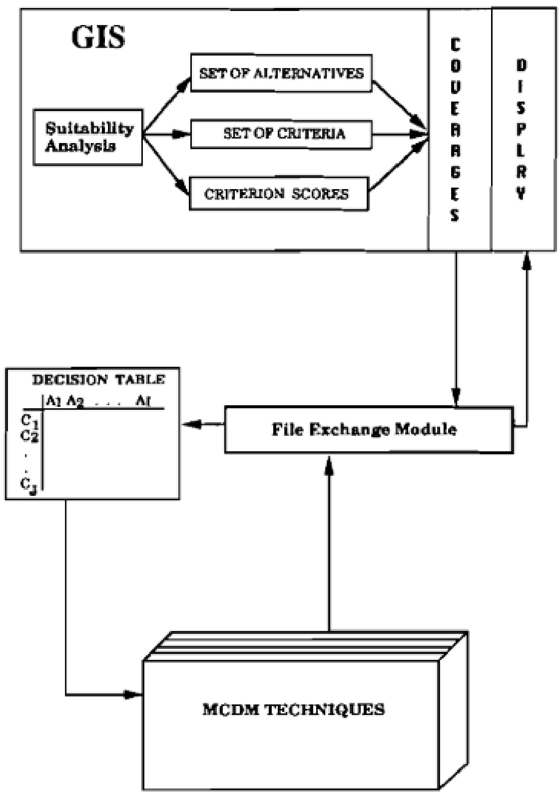


Figure 3.5. The structure of the analysis with GIS (Jankowski 1995).

In the following section, evaluation of each parameter and the judgement behind of each region were discussed more precisely.

3.2. Evaluation of Parameters

By considering literature survey and specific features of the regions, the factors that affect the site selection are accumulated under three essential headings as following table with their subfactors:

Table 3.1. The selected parameters affecting the site selection for WECs in Turkey.

1	**Technical Parameters**	Wave Power
		Sea Depth
		Vicinity to Electrical Transmission Line
2	**Environmental Parameters**	Marine Protected Areas
		Fishing Activities
		Military Exercise Areas
3	**Socio-economic Parameters**	Population Served
		Distance to Ports
		Vessel Density

3.2.1. Technical Parameters

3.2.1.1. Wave Power

Existed energy in the region, definitely is the most important aspect for siting WECs. Therefore, for three seaside of Turkey, Black Sea, Mediterranean Sea and Aegean Sea, many researches has been reviewed and some of them are involved to this study for the evaluation of wave energy.

Articles for Black Sea region, which are involved to gain information about wave energy potential for the area, are listed below;

1. Akpınar et al (2017) have studied long term evaluation of wave power in the Black Sea (Figure 3.6) and details of their study as below:
   - Dataset of the article covers the period of 1979 to 2009, approximately 31 year
   - Third generation SWAN model was used by using CFSR wind data.
   - Distribution of annual wave power is shown below figure.

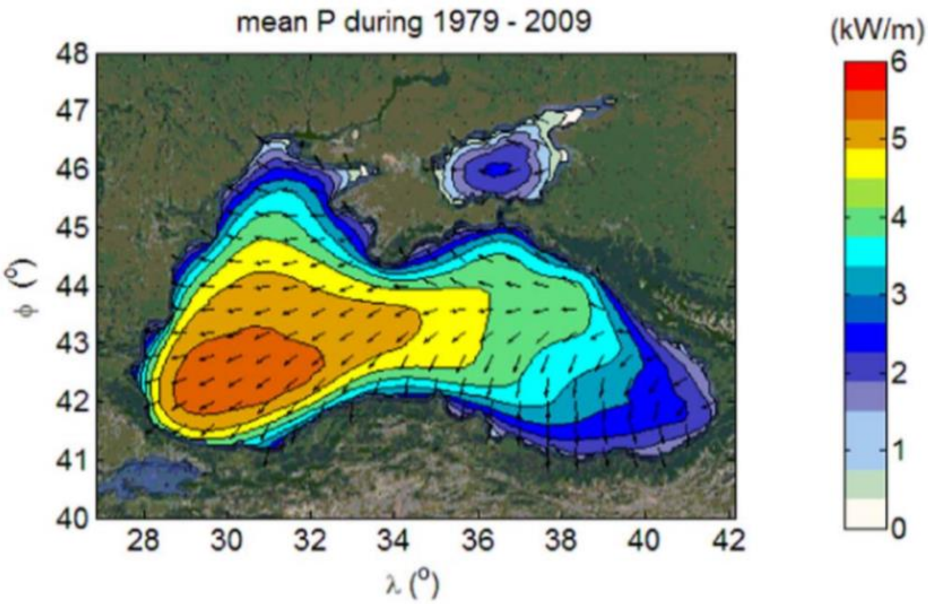


Figure 3.6. Distribution of wave power (Akpınar et al. 2017).

2. Akpinar and Kömürcü (2013) have simulated wave energy of Black Sea (Figure 3.7) and technical details are described below:
   - Utilized numerical model was SWAN for hindcasting of desired wave parameters.
   - Wave parameters were hindcasted for 15 years between 1995-2009.

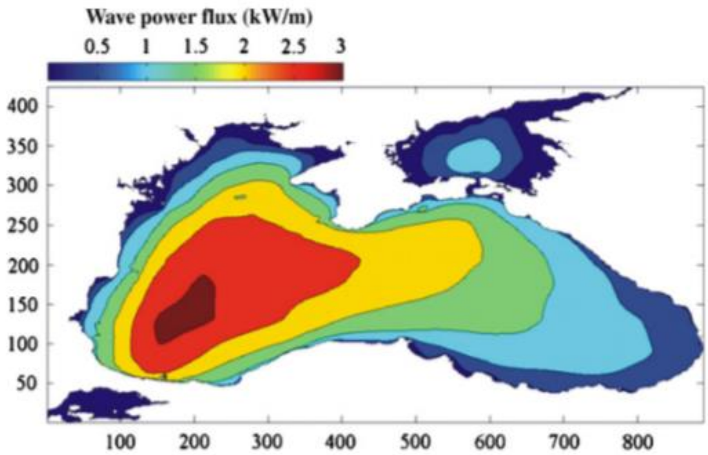


Figure 3.7. Annual mean wave power flux (Akpinar and Kömürcü 2013).

3. Aydoĝan et al (2013) were carried out a study in order to determine wave energy potential of Black Sea (Figure 3.8) and technical informations of their study as below:
   - The wave model used for hindcasting was Mike 21 SW.
   - Average wave power is observed as 7 Kw /m at the most powerful site (Figure 3.8).

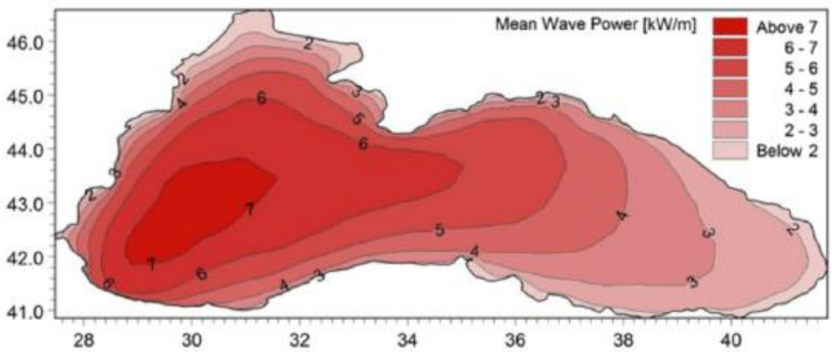


Figure 3.8. Wave power distribution of Black Sea (Aydoĝan et al. 2013).

4. Rusu (2015) also studied wave energy potential of Black Sea (Figure 3.9) with the below tehcnical details:
   - The model used in this study was SWAN driven by CFSR wind data.
   - Hindcasting was carried out between 1999-2013.

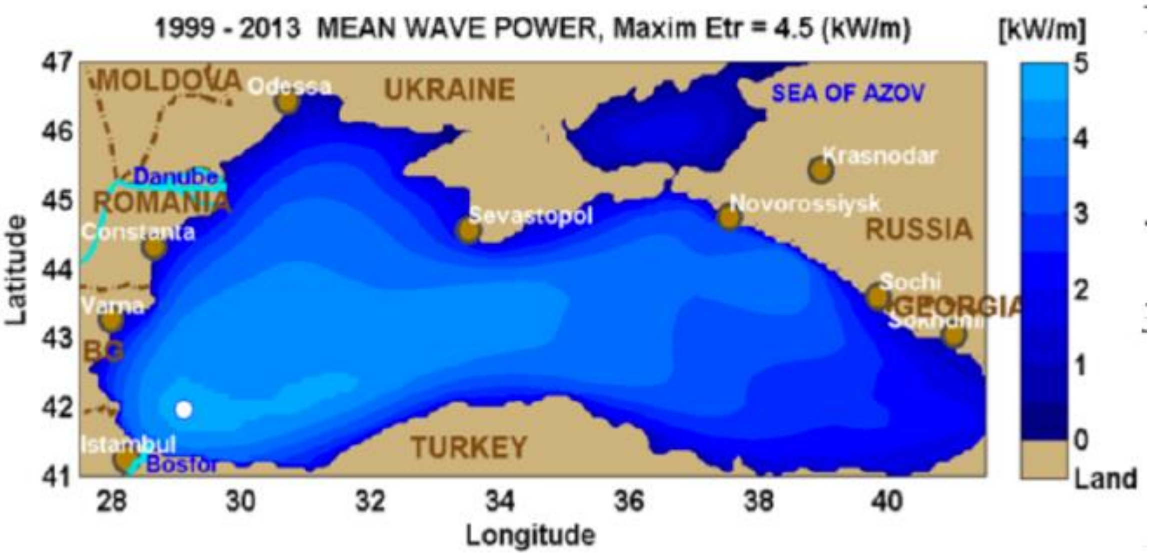


Figure 3.9. Wave power distribution between years of 1999-2013. (Rusu 2015)

Articles that are used for the evaluation of wave power potential for Mediterranean coastals of Turkey are listed below;

1. Besio et al (2016) carried out a study to determine wave energy potential of Mediterranean Sea (Figure 3.10) and technical details of their study as below:
   - The hindcast, covering the period of 1979-2013, was obtained by using Wavewatch III.

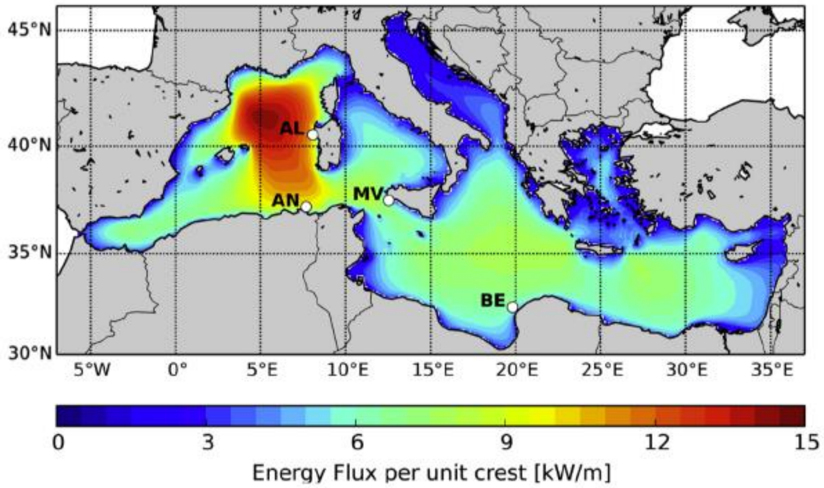


Figure 3.10. Distrubiton of mean wave power for the period of 1979-2013 (Besio et al. 2016).

2. Liberti et al (2013) studied in Mediterranean in order to estimate wave energy flux (Figure 3.11) and technical details of their study are described below:

- The study was implemented in the period of 2001-2010.
- The numerical model used in the study was WAM cycle 4.5.3.

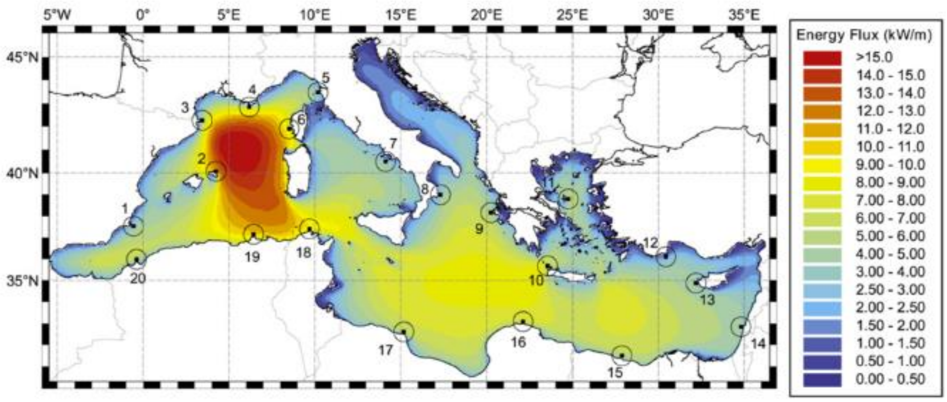


Figure 3.11. Distribution of mean wave power for the years of 2001-2010 (Liberti et al. 2013).

3. Zodiatis et al (2014) were also carried out a study for the wave power assessment of the Eastern Mediterranen Sea (Figure 3.12) with the following details:

- Wave parameters were hindcasted for 10 year covering the period of 2001-2010.
- The numeric model was WAM.

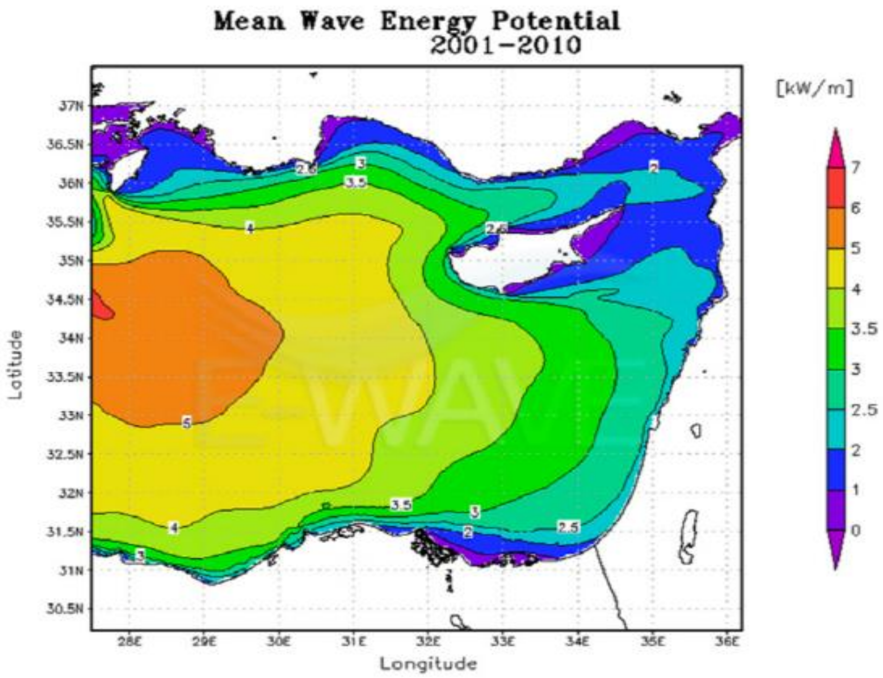


Figure 3.12. Distribution of wave power (Zodiatis et al. 2014).

4. Ayat (2013) studied wave power potential in the Eastern Mediterranean (Figure 3.13) in conjuction with following details:

- Third generation spectral wave model Mike 21 was implemented.
- Dataset covering the period of 1994-2009 and wind data were taken from the European Center of Medium Range Weather Forecasts (ECMF).

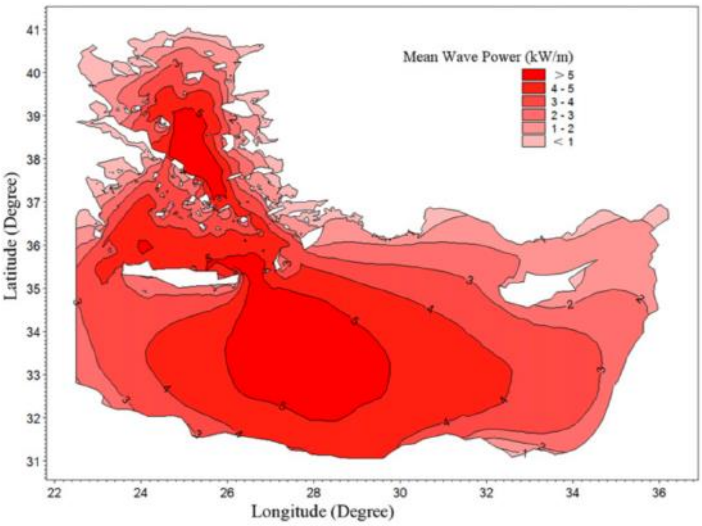


Figure 3.13. Mean Wave Power Distributions (Ayat 2013).

After having reviewed the literature, wave power of each cell was determined in a specific way according to the aforementioned articles. First of all, simulation results of each study were superposed with the generated map in ArcGIS with the help of Geo-referencing tool. After that, transparency of the overlaid picture decreased to observe the wave power potential of each cell. Exemplification of wave powers provided in the articles and their visualization in GIS environment are presented in Figure 3.14, Figure 3.15 and Figure 3.16. From these observations a wave power potential value was assigned to each cell and minimum and maximum values are determined (see Table 3.2) in order to standardize each cell between 0 and 1 according to these lowest and highest values.

Table 3.2. Minimum and Maximum Values of Mean Wave Power

Value	*Mean wave power*
Maximum	4.81
Minumum	0.31

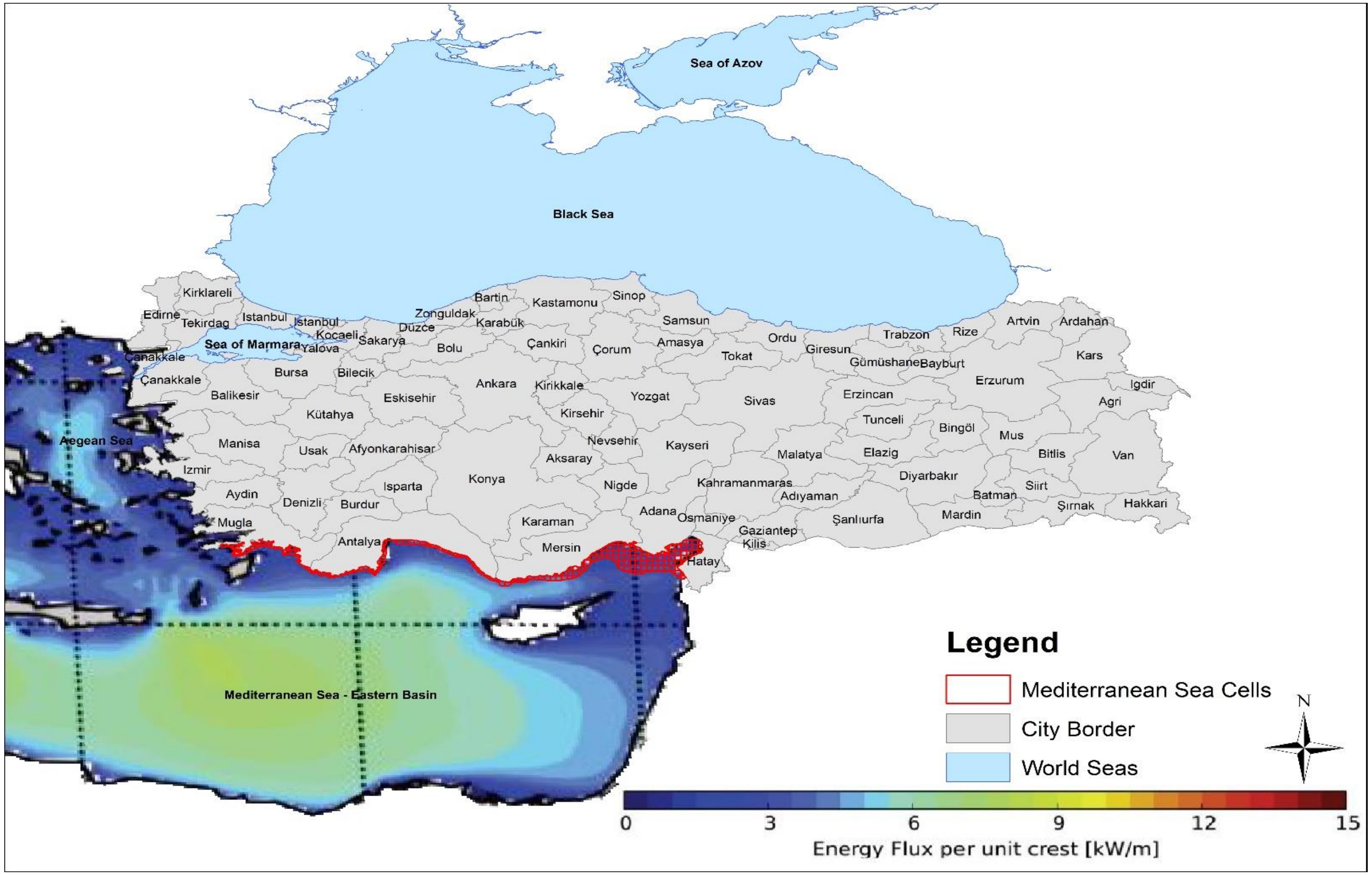


Figure 3.14. Estimation of wave power potential of each cell according to the studies of Besio et al (2016).

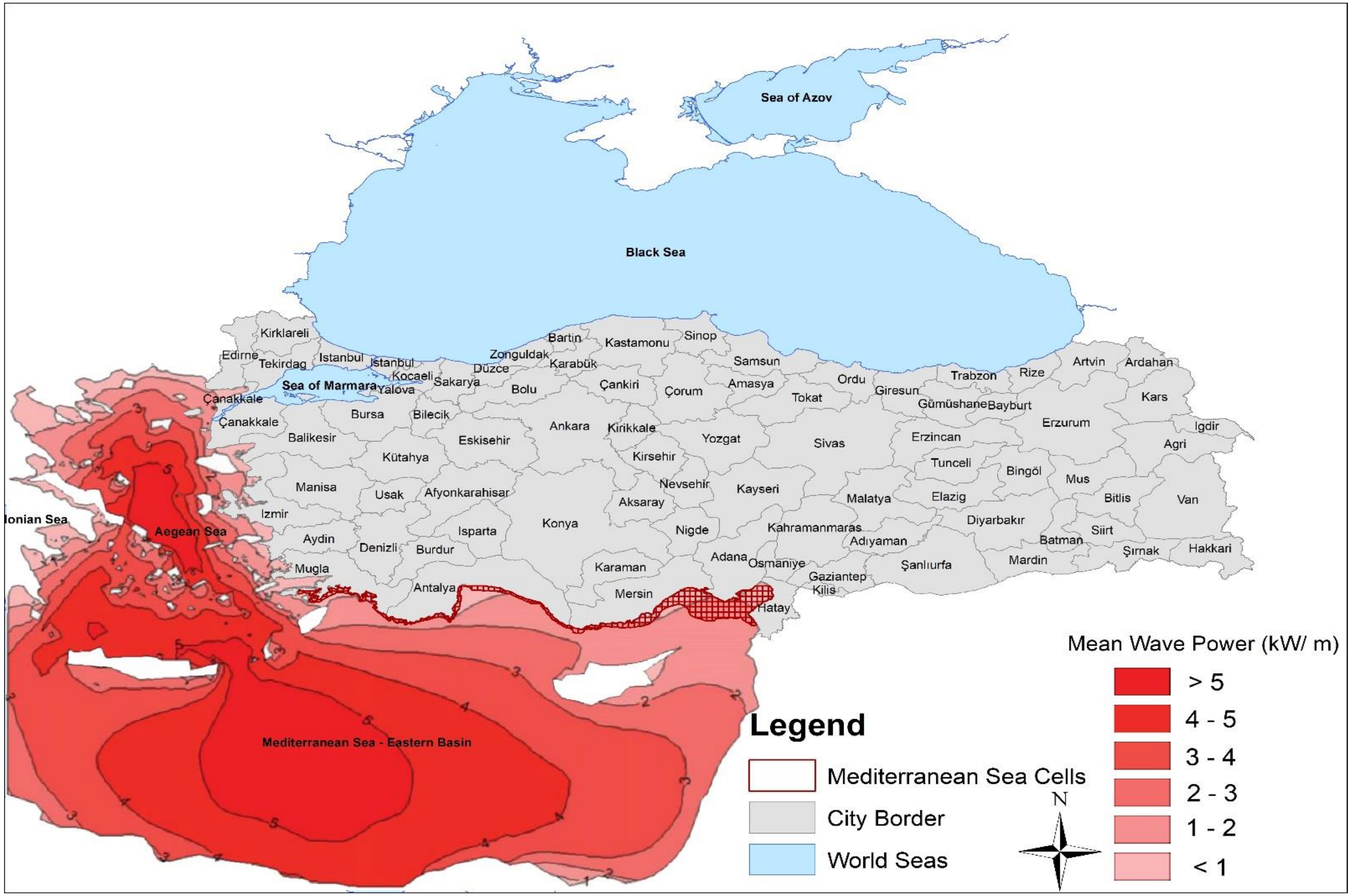


Figure 3.15. Estimation of wave power potential of each cell according to the studies of Ayat (2013).

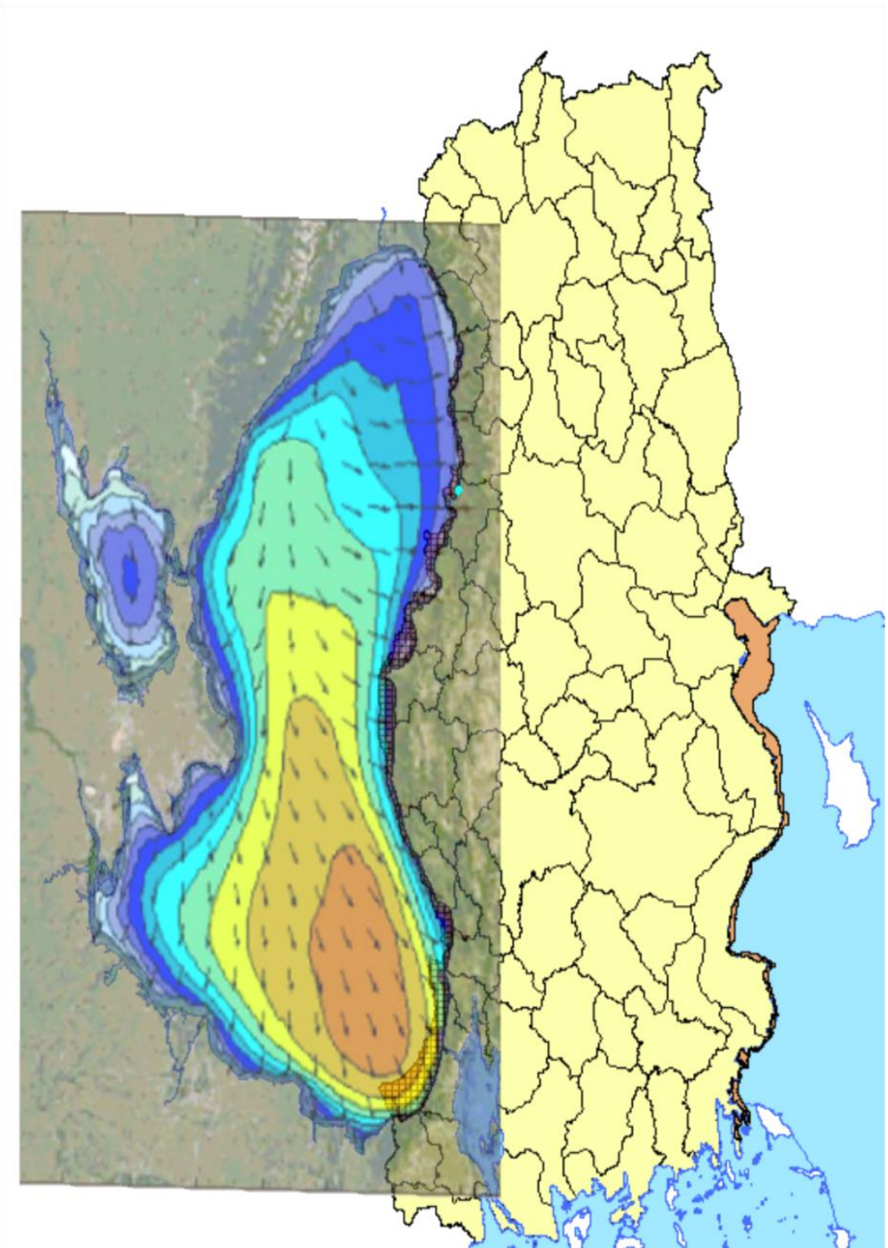


Figure 3.16. Estimation of wave power potential of each cell according to the study of Akpınar et al (2017).

3.2.1.2. Sea Depth

Depth of the sea is an important technical parameter while during both installing phase and after the operation. First of all, since depth of 200 m determine the continental shelf of any coastal country as well as current technologies are not feasible for the deep water installations, the study was suspended with depth of 200 m. Also, most of the waves are broken in relatively shallow water, which means waves lose their significant part of energy, therefore, shallow waters were found as least preferable areas for the study region. However, as deep water may also increase the investment costs, optimal depth for WECs neither become in the too much deep nor become in the shallow waters. Anorther important issue with the depth of the sea is that this study mainly focuses on offshore type of wave energy converters since most of the marine uses are carried out in nearshore zone. Hence when determining the internal significance level of the regions, offshore type of WECs are found relatively more suitable comparing to nearshore type of WECs, therefore, regions having low water depths were found as the least preferable areas as shown in Table 3.3.

In the study, four depth contour were drawn on GIS environment (see Figure 3.17) with the dataset provided by GEBCO. After that for each gridded cell, depth of the sea was graded according to in which interval they are.

Table 3.3. Internal score of Sea Depth

Depth Range	*Significance Level*	*Score*
0-50 m	Least Preferable Region	0.25
50-100 m	Most Preferable Region	1
100-150 m	Preferable Region	0.75
150-200 m	Weak Preferable Region	0.5

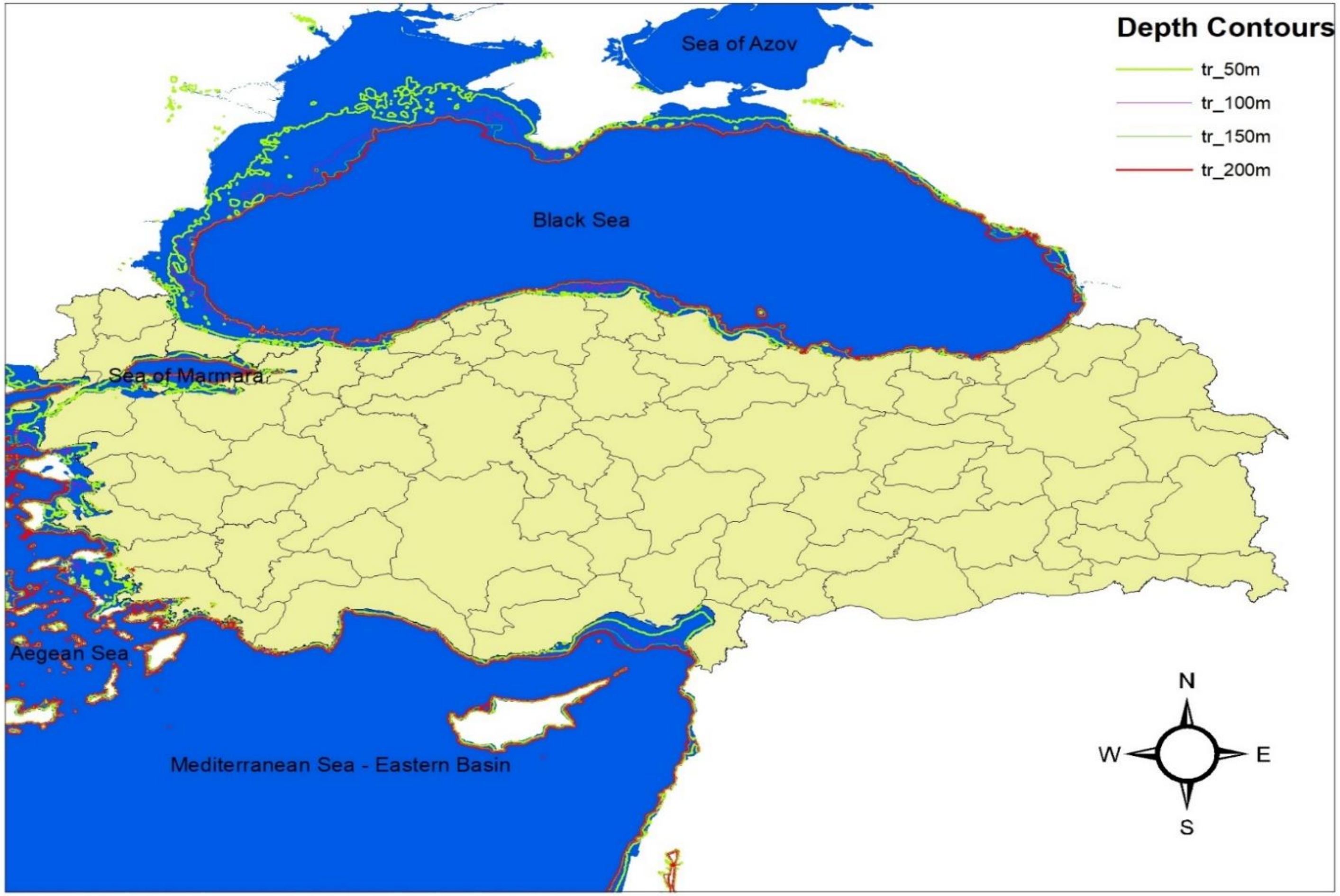


Figure 3.17. Depth Contours of Turkey Seas (https://www.gebco.net/)

3.2.1.3. Distance to Electrical Transmission Line

Since the distance from main transmission line directly related with the cabling costs, availability of the transmission line is involved to the analysis. Therefore, dataset provided by TEİAŞ, is used to evaluate adjacency of main transmission line. In order to evaluate each cell in GIS environment, Buffer tool was employed for the observations of distances to the transmission line (Figure 3.18).

To be able to provide feasible project economically, regions are standardized according to the vicinity to each buffer as shown in Table 3.4.

Table 3.4. Internal Score of Vicinity to Transmission Line

Distance Range	Score
0-10 km	1
10-20 km	0.86
20-30 km	0.72
30-40 km	0.58
40-50 km	0.44
50-60 km	0.3
60-70 km	0.14

As mentioned in the previously, since vicinity to main transmission line decrease the cabling cost, it is considered to install WECs close to electrical grid locations. Electricity produced from a WEC cannot be connected to the station less than 33 or 66 Kv. (Prest et al. 2007) Therefore this study involved main transmission line with the capacity of approximately 154 kV (see Figure 3.19) which is enough to carry electricity transmitted from wave energy farm.

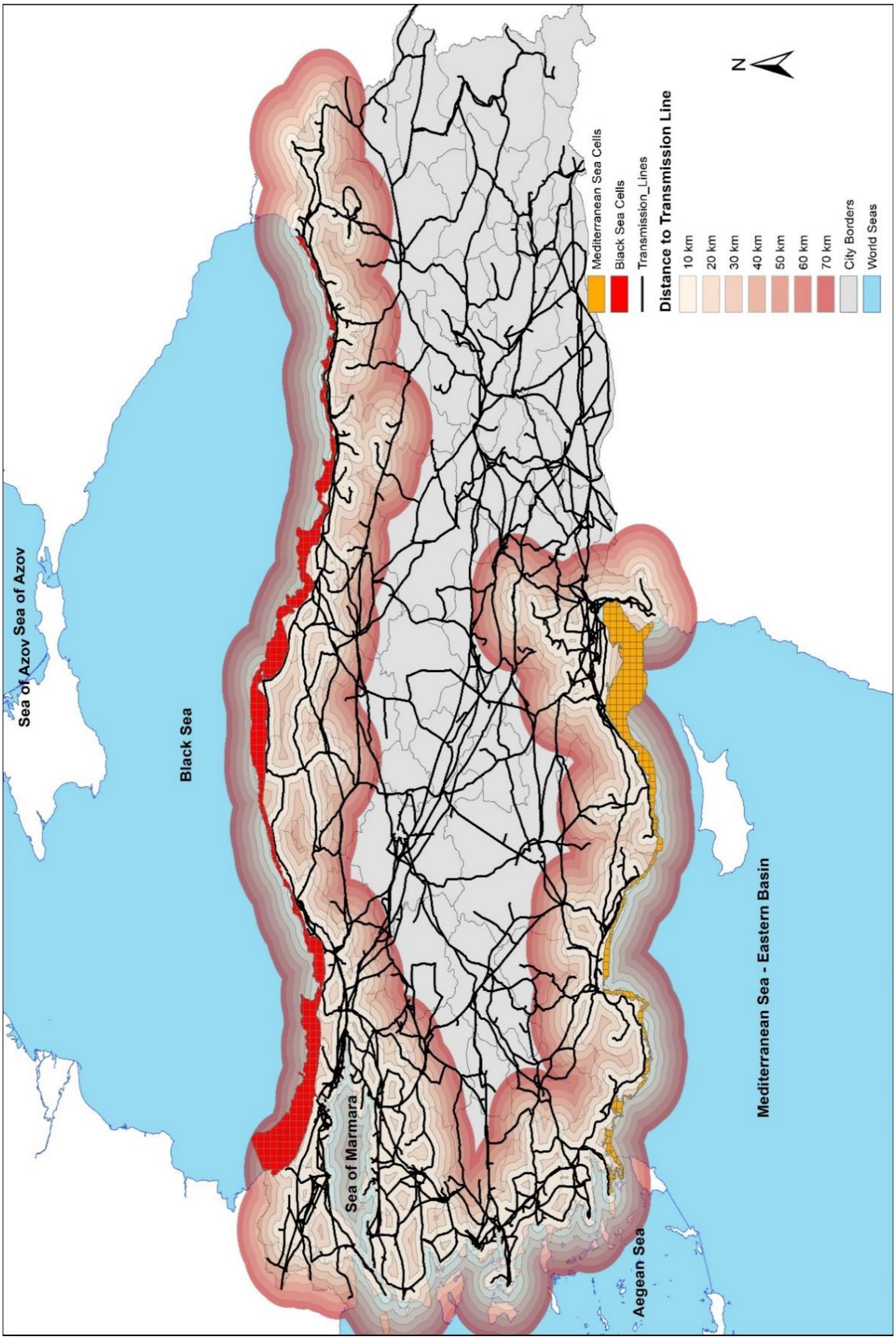


Figure 3.18. Transmission Lines (154 kV) of Turkey (https://www.teias.gov.tr/).

3.2.2. Environmental Parameters

3.2.2.1. Marine Protected Areas

The protected areas in marine region are another restrictive factor since it is impossible to deploy WECs to these regions. Therefore, these regions were determined with dataset provided by Republic of Turkey Ministry of Environment and Urbanization (Figure 3.19). After determination of the MPAs, all the grided cells encountered with the protected areas are excluded from study by assigning “0” index value.

Figure 3.19. Natural protected regions in Turkey (https://tucbs.atlas.gov.tr/starter.aspx)

3.2.2.2. Military Exercise Areas

The marine regions which are designated as specific military zones, were seen as unsuitable regions in the study. These areas were manually drawn on GIS as a layer using coordinates given in website of Turkish Naval Forces Office Of Navigation, Hydrography and Oceanograph (www.shodb.gov.tr) as notice to mariners for no sailing zones (Figure 3.20). Therefore these regions were eliminated from the analysis by giving them a zero index value.

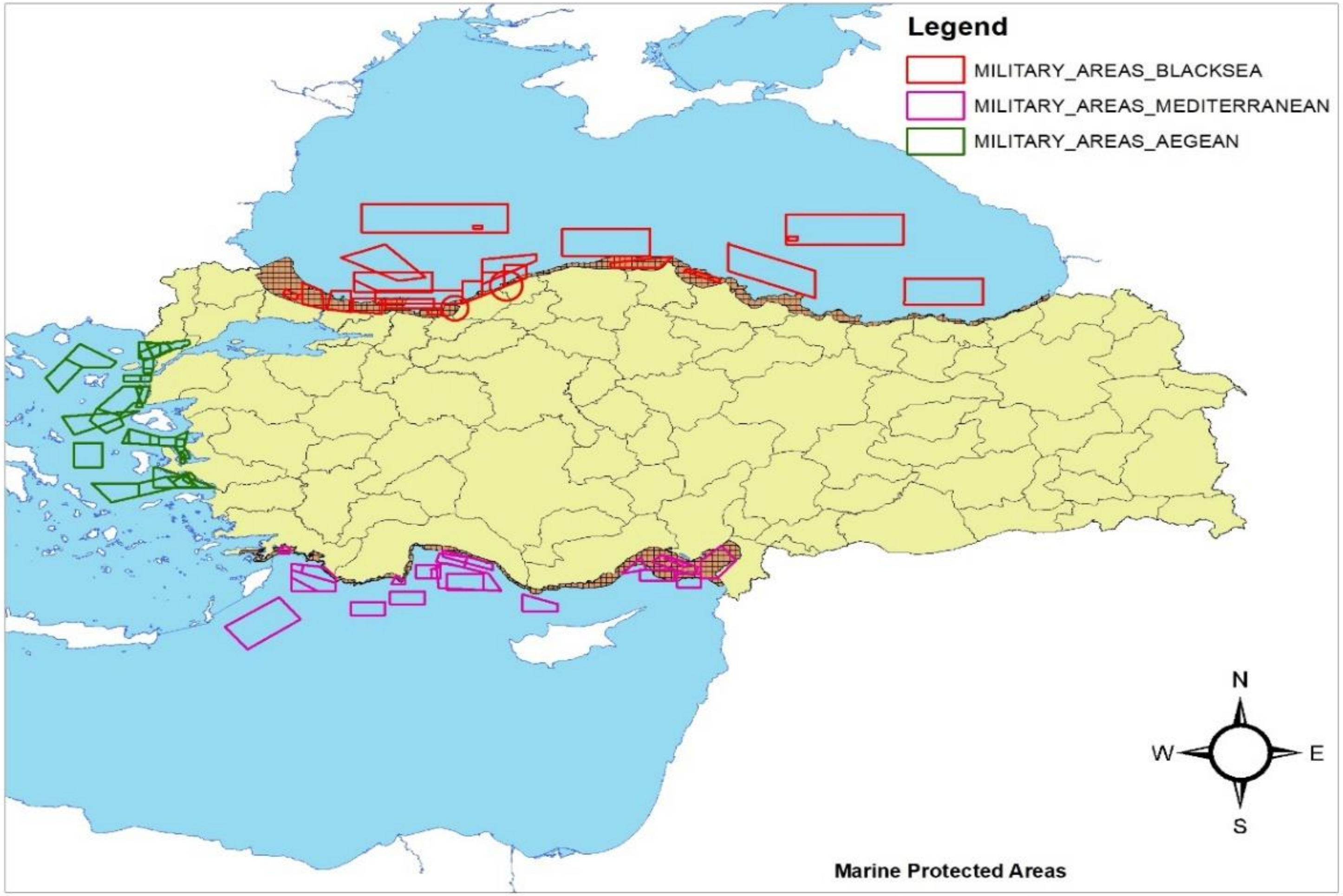


Figure 3.20. Military training areas of Turkey coastals. (www.shodb.gov.tr)

3.2.2.3. Fishing Activities

Since fishing is an important value of the most of the coastal cities, it is important to consider these regions as unpreferable regions. Therefore, these regions were categorized with the data provided by European Marine Observation and DataNetwork (EMODnet). To do that, image data superposed with the created map in ArcGIS (see Figure 3.21 and Figure 3.22) and after that each cell were weighted according to whether they are within the zone of fishing activities or not, by giving them an index value of “0” and “1”.

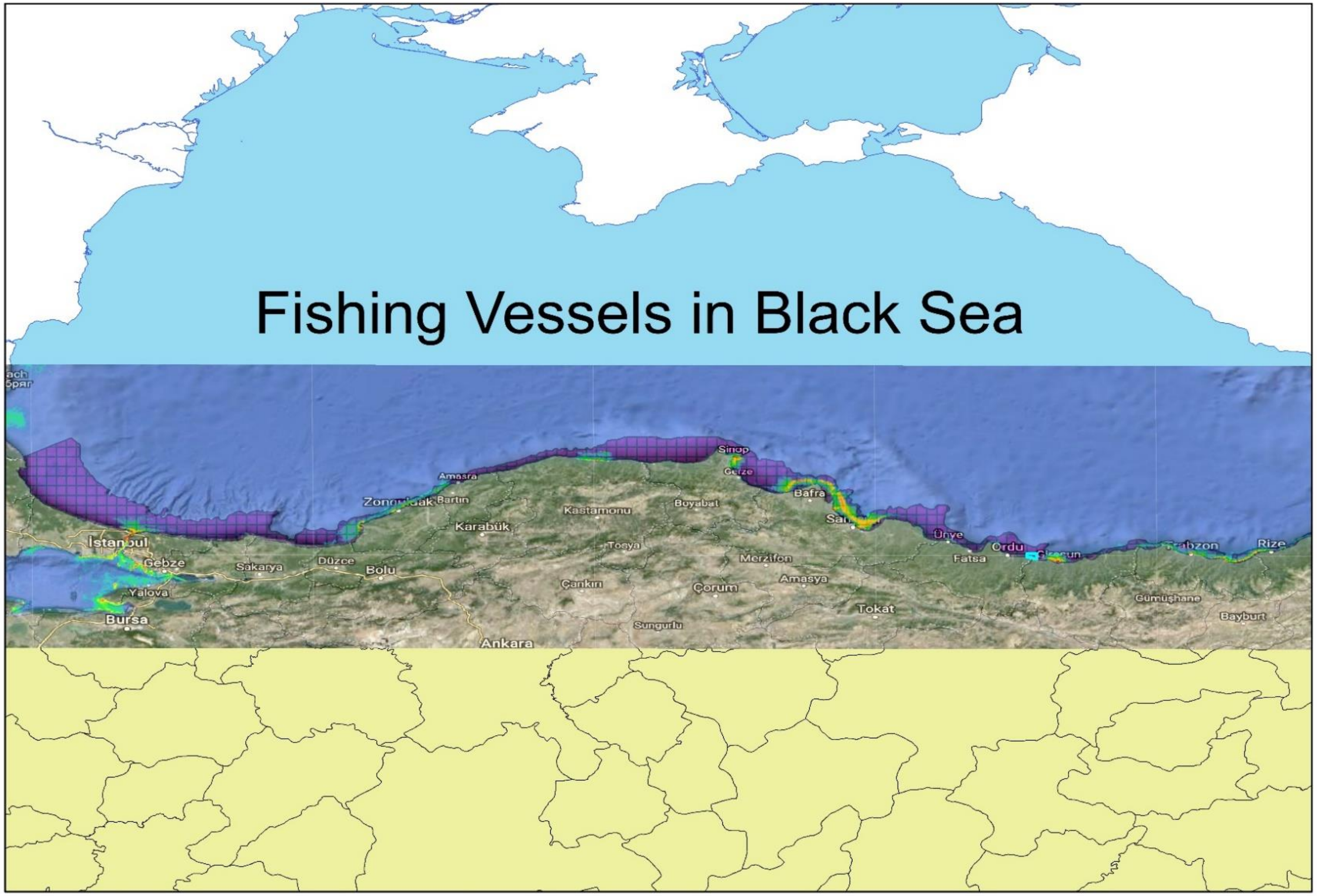


Figure 3.21. Fishing activities in Black Sea (https://www.emodnet-humanactivities.eu/view-data.php).

Figure 3.22. Fishing activities in Mediterranean Sea (https://www.emodnet-humanactivities.eu/view-data.php).

3.2.3. Socio-Economic Parameters

3.2.3.1. Population Served

The population that may potentially utilize from the generated electricity is also essential for the socio-economical acceptability of the project. Therefore, in the study preferability of the region considered directly related with the amount of the coastal province population that could provide service.

Classification of the population density was carried out in ArcGIS as it is already provided. In ArcGIS, there are seven classification methods called Manual, Equal Interval, Defined Interval, Quantile, Natural Breaks (Jenks), Geometric Interval and Standard Deviation as shown in Figure 3.23. In this study, Natural Breaks (Jenks) method was used. This classification method determine the breakpoints of groups and patterns settled in the data. Jenks (1967) (as cited from Osaragi 2002) mentioned that Natural Breaks is a widely used classification method in the GIS environment which reduce the variation within the group of data.

The reason for choosing this method is mainly loss of information relatively less than other methods when the breaking points are clear as it is also validated in Osaragi (2002) study shown in Figure 3.24.

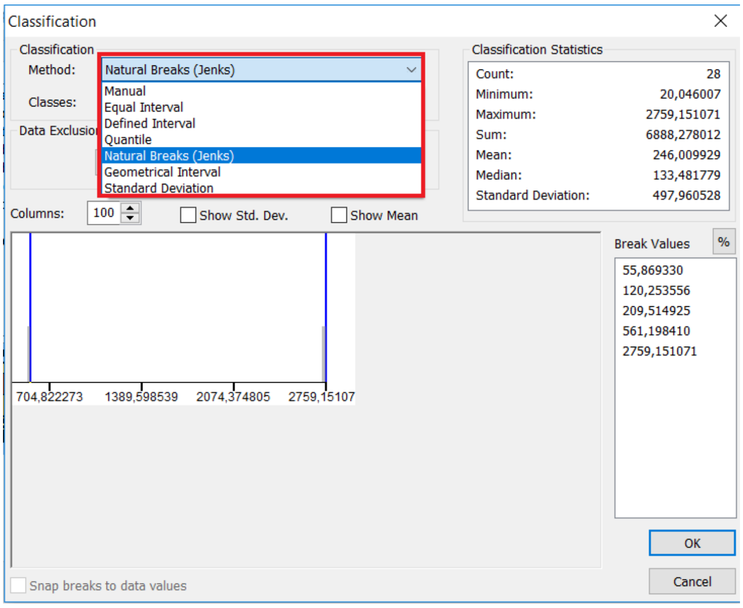


Figure 3.23. Classification methods provided in ArcGIS

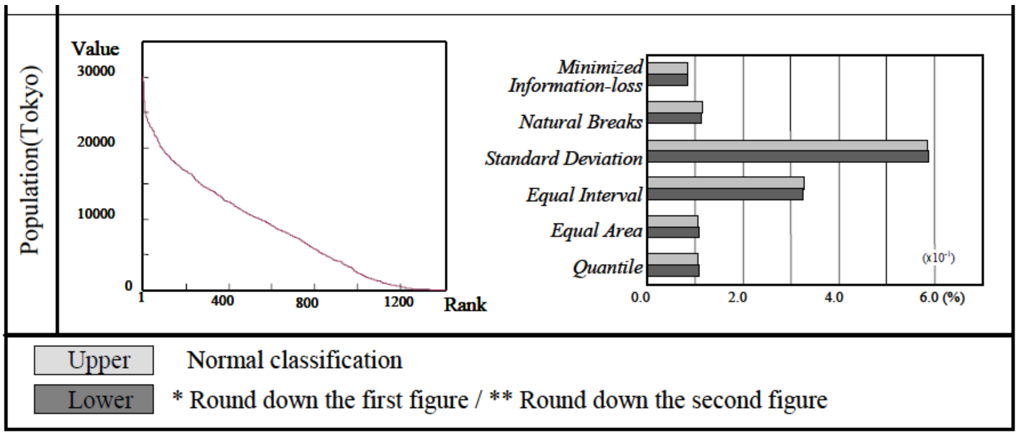


Figure 3.24. Information Loss Comparison of the Classification Methods. (Osaragi 2002)

In the study, density of the population are categorized in five groups and according to these categories standardization process were carried out as Table 3.5 since the difference between the lowest and highest value is too much which the least coastal population density is 20 (population/area) and the high populated region is approximately 2760 (population/area). Hence, categories of population density is shown in Figure 3.25.

Table 3.5. Evaluation of Population Density

Population Service Range	Score
20<x<56	0.2
56<x<120	0.4
120<x<209	0.6
209<x<561	0.80
561<x<2760	1

The reason using the population density not the population is that serving electricity generated from wave farm to discrete settlement is economically not feasible. Therefore, in the study population density was used instead of population. Considering the region high populated but provide far living space, it is proper to choose the regions according to their density of population in order to decrease the cost of the project.

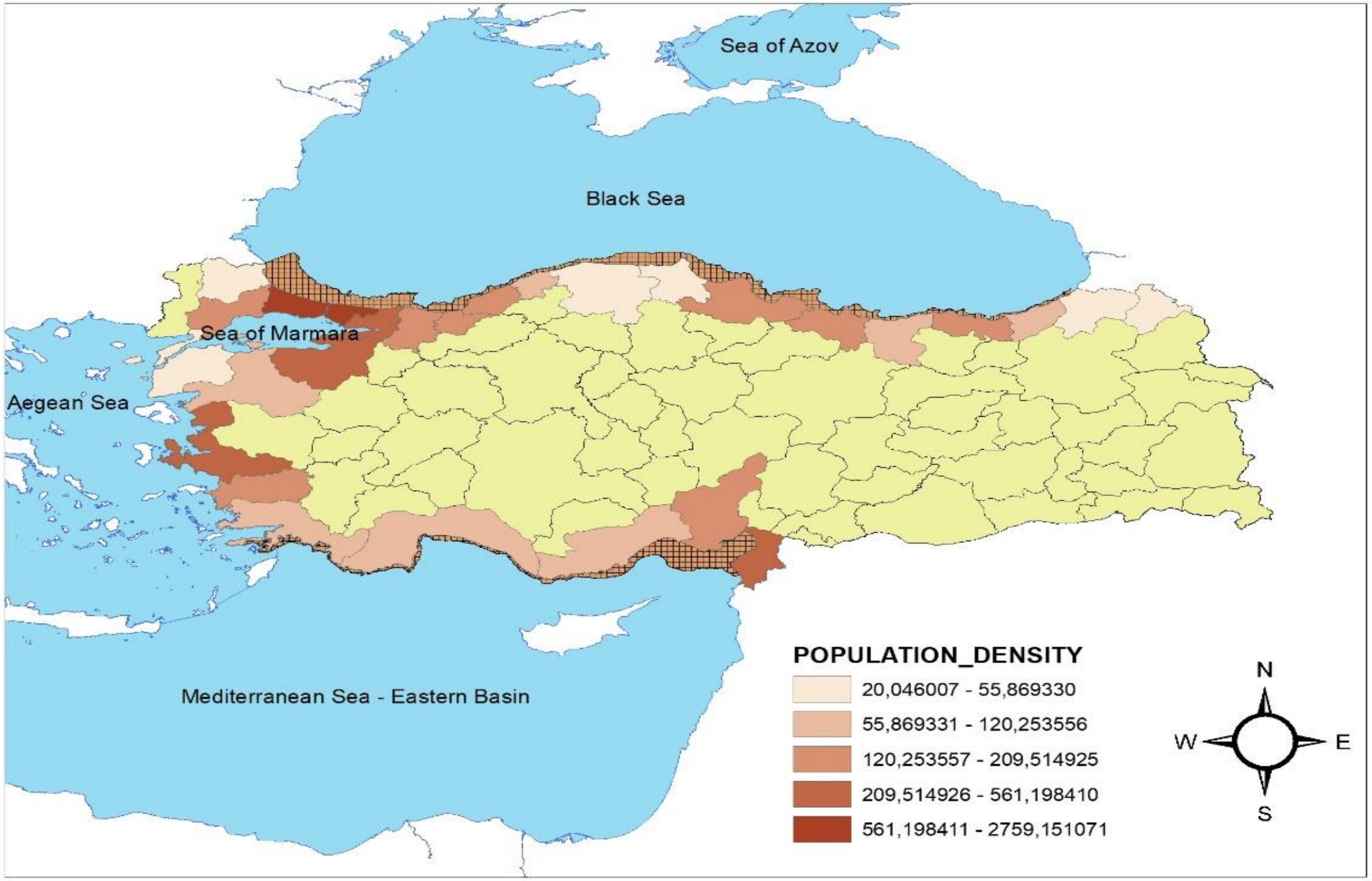


Figure 3.25. Population Density of the Coastal Regions of Turkey (http://www.tuik.gov.tr/Start.do).

3.2.3.2. Distance to Ports

As explained in the literature section, in order to satisfy technical requirements during the whole life of the project, proximity to vessel facilities essential step for the success of the project.

In the study, in order to execute internal classification of ports according to their distance to the regions data, location of the 43 essential port were taken from the website of https://www.searoutes.com/country-ports/Turkey (Figure 3.26). After that proximity to ports separated into six classes in ArcGIS with the help Buffer tool. These classes indicate the conformity of the each cell with the standardized values differing from 0 to 1. The weighted classes and their scores as shown in Table 3.6.

Table 3.6. Internal evaluation of Distance to Ports

Distance to Ports	Score
0-25 km	1
25-50 km	0.85
50-75 km	0.68
75-100 km	0.51
100-125 km	0.34
125-150 km	0.17

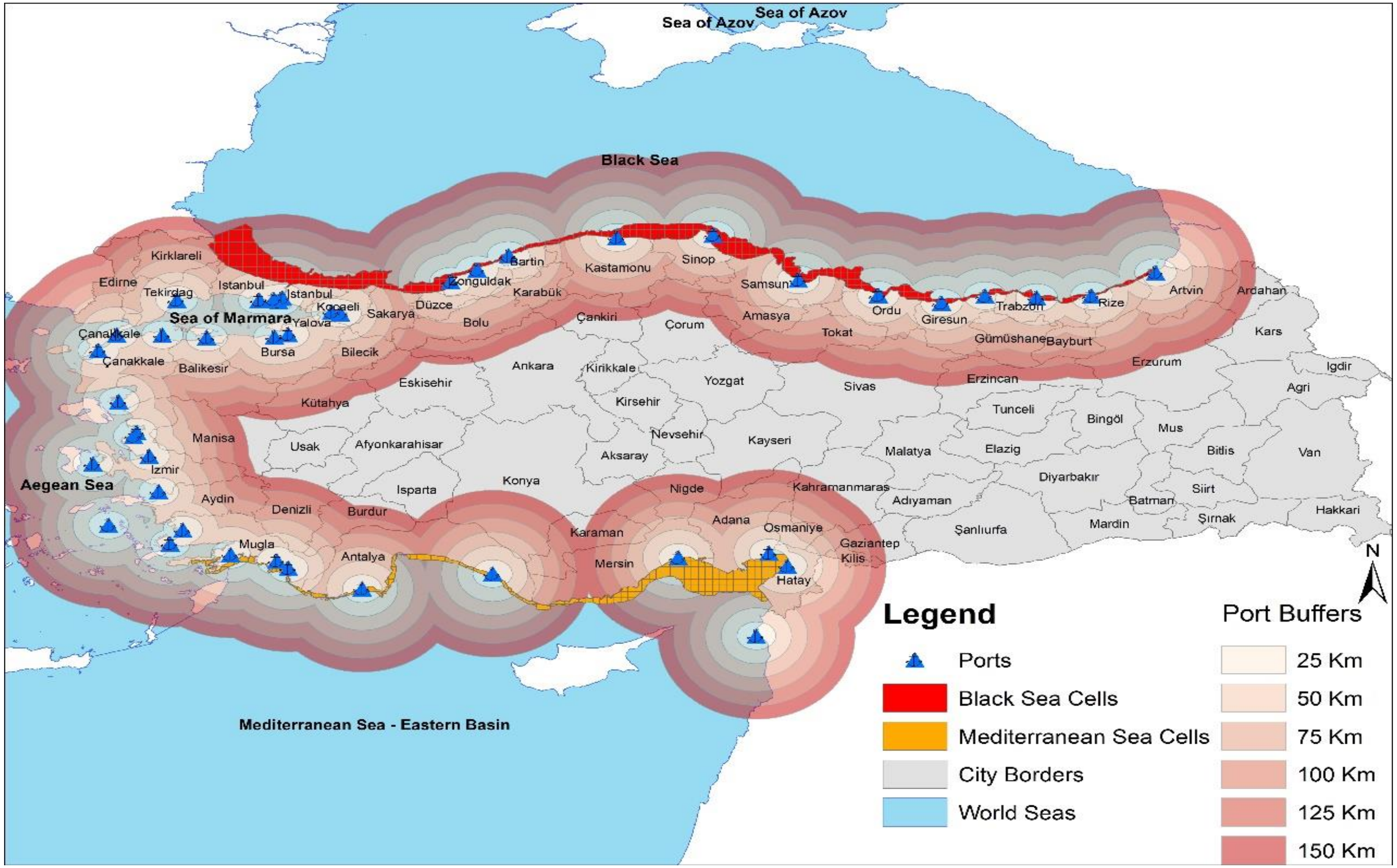


Figure 3.26. Proximity to Ports (https://www.searoutes.com/country-ports/Turkey).

3.2.3.3. Shipping Density

Since navigation routes may increase its density in some region, these regions were categorized in order to decrease the probable interference with wave power plants. Data provided by European Marine Observation and Data Network (EMODnet) was superposed with the map created in ArcGIS. After the creation, each cell were standardized as Table 3.7 according to their colour presented in Figure 3.27. As it is seen from Figure 3.26 the areas with high shipping density was considered as least preferable regions and index factor of "0.2" was assigned while other regions were considered as relatively less occupied and sorted according to Table 3.7.

Table 3.7. Standardization of Shipping Density According to Colour of the Region

Colour Classification	Score
Blue	1
Dark Green	0.8
Light Green	0.6
Yellow	0.4
Red	0.2

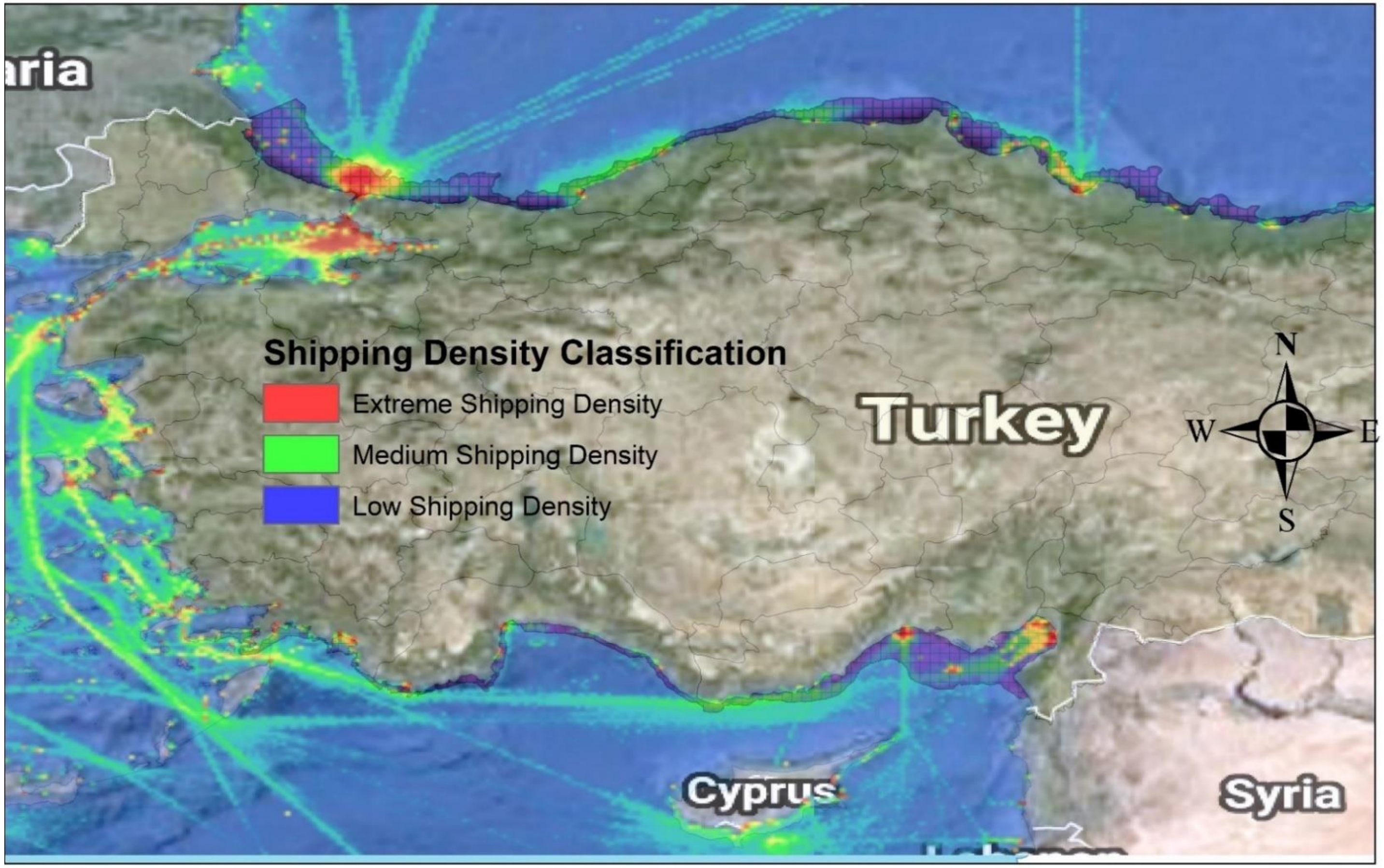


Figure 3.27. Yearly Averaged Vessel Density of Turkey in GIS Enviorenment.(https://www.emodnet-humanactivities.eu/view-data.php).

3.3. Methodology Behind the Discussions

After having defined the method for the evaluation of each parameter as well as decision making method used in this study, the study covers two different discussions as mentioned well up on the methodology section. In order to have these discussions, some of the parameters were used to understand whether the region is interfering with other uses or not and these factors are called as "Exclusion Parameters" as shown in Table 3.8. So that, for the entire study region, index value of "0" or "1" was assigned according to whether they are unsuitable or suitable, respectively. For example, if the area is in the border of protected areas specified by the government, then this area is seen as unsuitable for the study as shown in Figure 3.28 and index value of "0" is assigned.

Table 3.8. Exclusion parameters used in the study

Exclusion Parameters	Weighting Factor
Military Exercise Areas	0 or 1
Marine Protected Areas	0 or 1
Fishing Activities	0 or 1

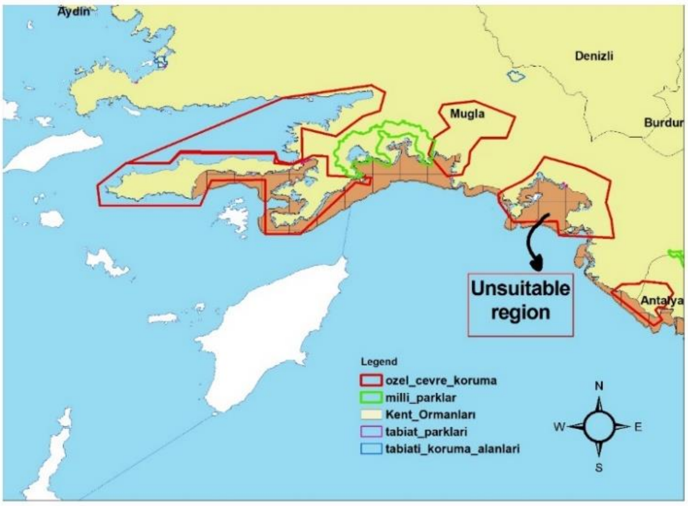


Figure 3.28. An example of unsuitable region

Other parameters utilized in the analysis are called as "Evaluation Parameters" as written in Table 3.9. and evaluation of these parameters described in the following section in a more detailed.

Table 3.9. *Evaluation parameters*

Evaluation Parameters
Wave Power
Proximity to Ports
Shipping Density
Population Served
Bathymetry
Vicinity to Electrical Grid

3.3.1. The First Discussion – Equal weight vs Weighted Parameters

The first discussion covers two case in which the selected parameters are weighted both equally and differently as shown in Table 3.10. and Table 3.11.

Table 3.10. Equal Weighting, Case-1

Evaluation Parameters	Weighting Factor
Wave Power	1/6
Proximity to Ports	1/6
Shipping Density	1/6
Population Served	1/6
Bathymetry	1/6
Vicinity to Electrical Grid	1/6

Table 3.11. Non-Equal Weighting, Case-2

Evaluation Parameters	Weighting Factor
Wave Power	0.4
Proximity to Ports	0.2
Shipping Density	0.1
Population Served	0.1
Bathymetry	0.1
Vicinity to Electrical Grid	0.1

In the case-1, the importance of all the parameters were considered as equal and index value of “1/6” was assigned to each of them. However, for the case-2, each of the parameters were evaluated as its own importance. When these parameters are assigned weights, extensive literature knowledge has been employed to provide accurate results.

Criteria of wave power was seen as the most important parameter and weighting factor of “0.4” value was assigned. The reason is that existency of the efficient region which may fulfill the energy demands of the nearby region is ultimate aim of all the energy investments. Therefore, importance rating of wave power is considered relatively more significant than all other parameters.

Proximity to a port has a significance importance either during the construction phase or after the commissioning the project as mentioned in literature section. Therefore this factor was weighted as the value of “0.2” which is two times more than the rest of the parameters as given in Table 3.11.

Although the parameters were evaluated by considering the literature and features of the region, they are adjustable for the desired case. Let’s consider, vessel facilities are already provided for the entire region so that proximity to ports might be less important in this case. Subjectivity and variability of these parameters conserve themselves in any case. Therefore, there is no restriction and a certain rule for determining and weighting factor, selected parameters may be altered for the intended region.

3.3.2. The Second Discussion – Sensitivity to Wave Power Input Data

As mentioned before, for the first discussion wave power is not the focusing point for the regions, therefore, average of wave power stem from the articles were calculated and included to the analysis in order to determine suitability index of the cells. However, in the second discussion, wave power of each article were included to the suitability analysis on its own, disregarding average of wave power come from presented articles. After that, suitability index of each cell calculated for wave power of each article. The reason for doing that is revealing a range of suitability index with differing wave power values. In this evaluation only non-equal weighting values were assigned to the parameters in order to concentrate on the alteration with differing wave power datasets.

CHAPTER 4

RESULTS

4.1. Results of the First Discussion – Equal Weight vs Weighted Parameters

Since most of the energy investment policies are organized with long term goals, awareness of the location-based precautions are imperative. Therefore, at the initial stage of the project acceptability of the technical, environmental and socio-economical factors should be provided in order to avoid possible conflictions which might come true as undesired. Considering this persperctive, in the earlier stage, estimation of convenient locations for the deployment of WECs into Turkey seas is much more important than wave power potential of the region. Therefore, the main goal of this study is to display that there are certain relationship between the factors when selecting a suitable region and learned knowledge of the different researchers were involved to select the best suitable site for Turkey. A model was developed for this purpose and the integration of MCDA and GIS was presented in Turkey seas.

As a result of the first discussion, suitable regions were determined both by giving equal weighting factor to each parameter and assigning different weighting factor to the selected parameters. When it is applied equal weighting factor to the evaluation parameters which is the first case of this study (see Table 3.10.), suitability index of the regions were distributed as shown Figure 4.1. In this case, Black Sea region in general is more suitable to wave energy application especially Western Black Sea near the Bulgarian coastline. Eastern Black Sea is also suitable but with a smallerarea for implementation. When the region is investigated rigorously, cell of 275 has the highest suitability index having approximately 0.83 as shown in Figure 4.1.

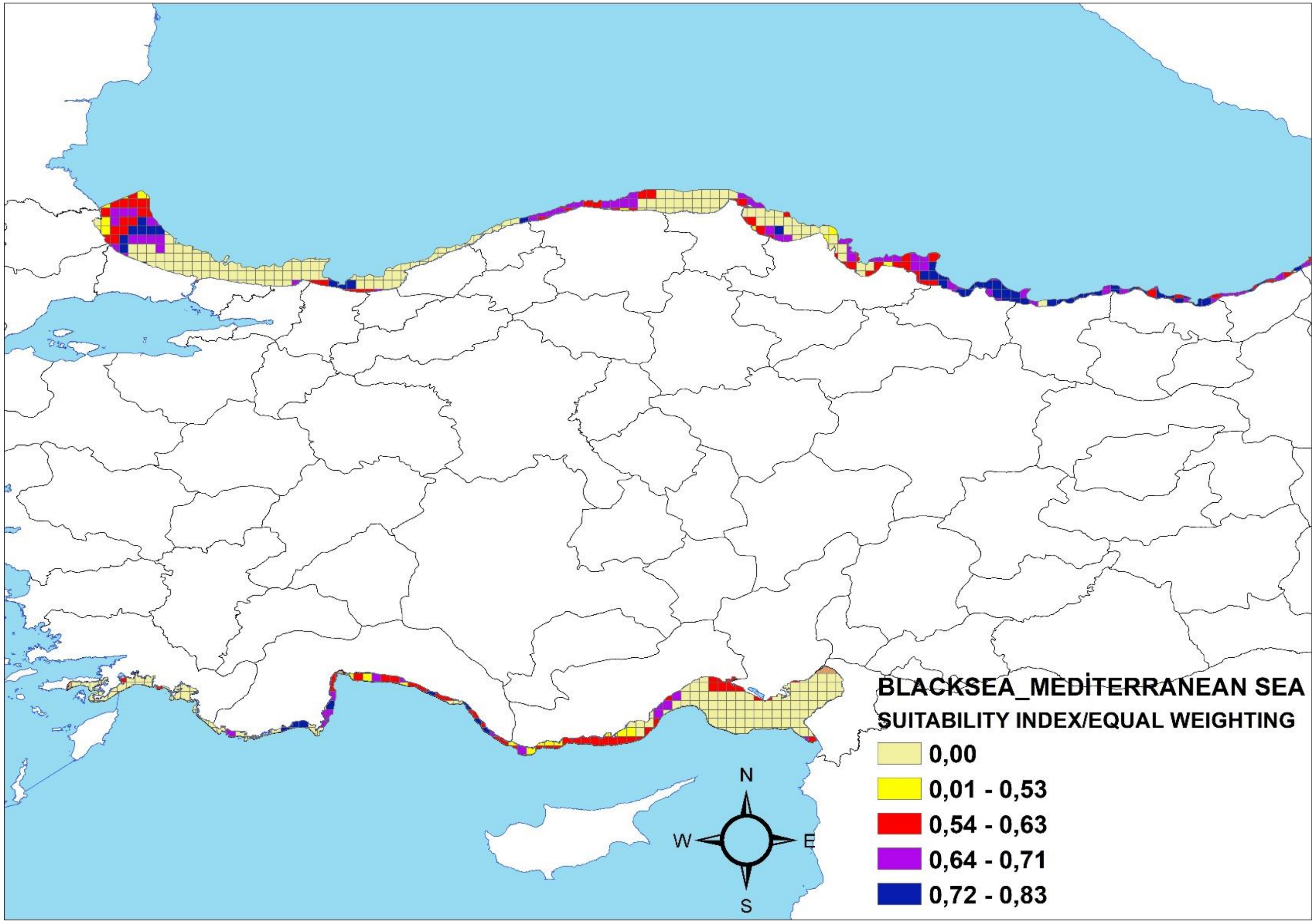


Figure 4.1. Categorization of suitability index for case-1, Equal Weighted

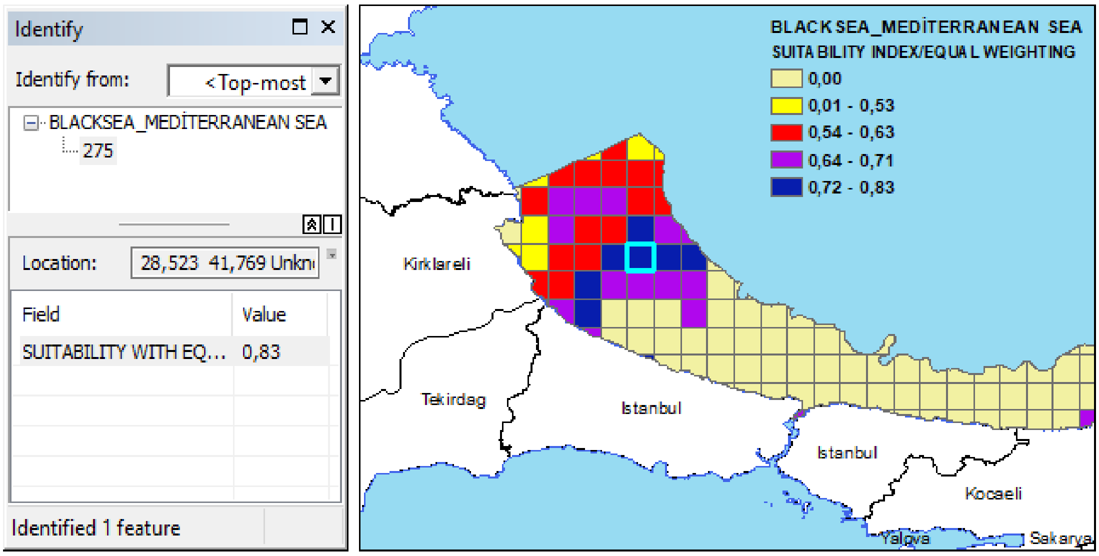


Figure 4.2. The region with highest suitability index in case-1

According to the results executed with equal weighting factors, five best suitable regions for Black Sea and Mediterranean Sea are provided in Table 4.1 with their suitability scores and coordinates.

Table 4.1. Five highest suitability score of regions with the equal weighting factor

	Black Sea Region Suitability Score	Coordinates	The Closest City	Mediterranean Sea Region Suitability Score	Coordinates	The Closest City
1	0.83	41° 46' 8.3994" N, 28° 31' 22.7994"E	Istanbul	0.76	36° 13' 58.7994" N, 30° 3' 43.2"E	Antalya
2	0.81	41° 46' 40.7994" N, 28° 37' 19.1994" E	Istanbul	0.75	36° 16' 58.8" N, 30° 11' 34.8" E	Antalya
3	0.79	41° 1' 4.8"N, 39° 57' 57.6" E	Trabzon	0.75	36° 17' 20.4" N, 30° 16' 58.8" E	Antalya
4	0.79	41° 4' 47.9994" N, 37° 30' 57.5994" E	Ordu	0.74	36° 28' 51.6" N, 32° 5' 9.5994" E	Antalya
5	0.78	40° 59' 9.5994" N, 38° 6' 50.3994" E	Giresun	0,74	36° 19' 40.8" N, 32° 11' 42" E	Antalya

When the model is initated with the differing weighting factor described in the second case, suitability index were distributed as Figure 4.3. In this case, it is observed that high suitability values are more densily populated in Black Sea region (particularly Western part) since existed wave power potential of this region is clearly higher than Mediterranean region. To be more precise, cell of 276 is the best potential site for WECs having 0.81822 of suitability index as it is seen on Figure 4.4.

Moreover, the specific features of the most eligible region is provided in Table 4.2. As it is seen from this table, although the wave power value is not the highest one (see Table 3.2), this region was estimated as the most potential site for the deployment of WECs which clearly validate the vision behind this study.

Table 4.2. Features of the best suitable region in case-1

Coordinates	**Average Wave Power**	**Proximity to Port**	**Population Served**	**Depth Range**	**Vicinity to Electrical Grid**
41° 46' 8.3994" N, 28° 31' 22.7994"E	4.5 Kw/m	50-75 km	561<x<2760	50-100 m	40-50 km

Consequently, results of the first discussion validates that when it is applied equal weighting factor to the parameters, the highest suitability index values of Black Sea and Mediterranean Sea are closing to each other, however, when the weighting values are assigned according to their importance level, the highest suitability values are diverging from each other. (see Table 4.1 and Table 4.3) The reason for that is mainly, importance level of wave power is dominating with the differing factor which causes to Black Sea to be more remarkable since wave power of Mediterreanean Sea is far below than Black sea. But still, the most suitable site for wave energy application is consistent for both approach which is the Western Black Sea near to the Bulgarian coasts.

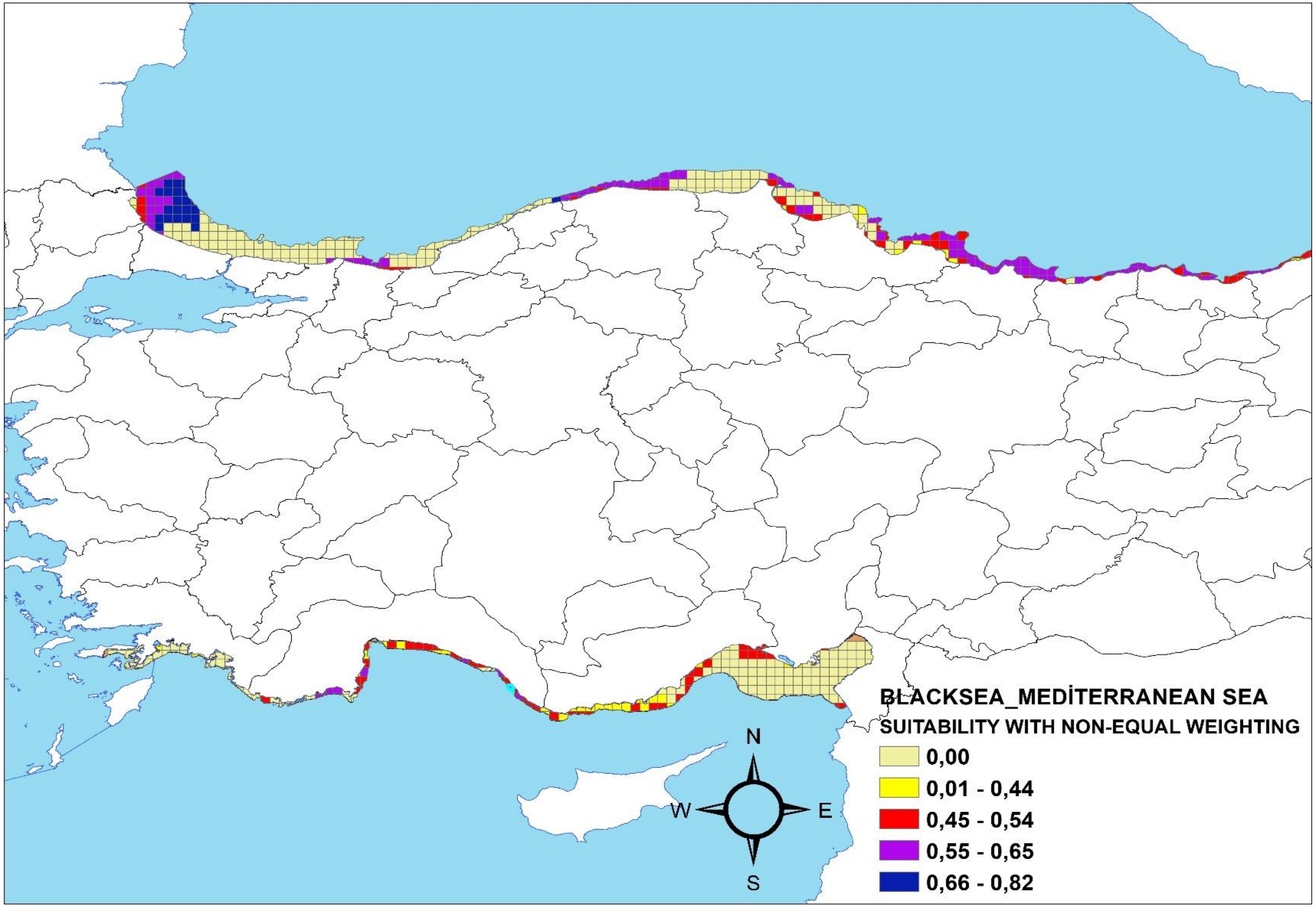


Figure 4.3. Categorization of suitability index for case-2, Differing Weighted

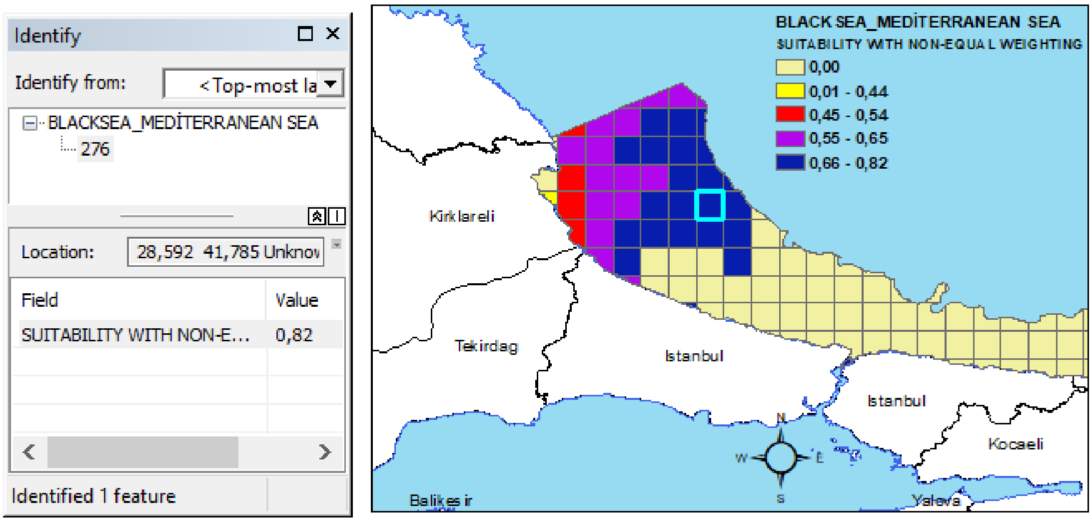


Figure 4.4. The region with highest suitability index in case-2, Differing Weighted.

Table 4.3. Five highest suitability score of regions with differing weighting factor

	Black Sea Region Suitability Score	Coordinates	The Closest City	Mediterranean Sea Region Suitability Score	Coordinates	The Closest City
1	0,82	41° 46' 40.7994" N, 28° 37' 19.1994" E	Istanbul	0,60	36° 13' 58.7994" N, 30° 3' 43.2"E	Antalya
2	0,82	41° 46' 8.3994" N, 28° 31' 22.7994"E	Istanbul	0,59	36° 19' 40.8" N, 32° 11' 42" E	Antalya
3	0,80	41° 45' 54" N, 28° 42' 39.5994 E	Istanbul	0,59	36° 16' 58.8" N, 30° 11' 34.8" E	Antalya
4	0,77	41° 51' 39.5994" N, 28° 30' 17.9994" E	Istanbul	0,58	36° 17' 20.4" N, 30° 16' 58.8" E	Antalya
5	0,75	41° 49' 40.8" N, 28° 40' 8.4" E	Istanbul	0,58	36° 14' 38.3994" N, 30° 8' 34.8" E	Antalya

After showing the regional results, it is also remarkable to display the categorical differences of the regions by applying both case-1 and case-2. In order to have this categorization, separated classes are sorted from one to five for each case in order to identify importance level of the category (Table 4.4).

Table 4.4. Identification of groups

EQUAL WEIGHTING SUITABILITY INDEX	NON EQUAL WEIGHTING SUITABILITY INDEX	GROUP OF CATEGORY
0	0	1
0.01-0.53	0.01-0.44	2
0.54-0.63	0.45-0.54	3
0.64-0.71	0.55-0.65	4
0.72-0.83	0.66-0.82	5

In Table 4.5 alteration of the categories of the regions in equal weighting case and differing weighting case were investigated and results in the equal weighting case show that 1.51 % of the regions decreased their category 2 step and 5.60 % of the cells decreased their category 1 step while most of the cells, 76.55 %, remained same. The main reason why many cells have not changed is basically most of the cells were already eliminated due to unfeasible conditions stem from the exclusion parameters. However, some of the regions which can be scored, were changed their category especially regions with high and low wave power potential because in the second case of the analysis, wave power is a dominant weighted parameter as shown in Figure 4.5,. This change is observed for those classes which show the transition from moderate to higher suitablility but the most suitable locations were still the same for both applications.

These changes in the results based on weighting approach indicates that it is very important to select correct weighting factors when designing suitability index method. But also the results show that even if the location is suitable for many parameters related to site selection, if there is less wave power potential, the feasability of such application would be questionable.

Table 4.5. Categorical differences based on equal weighting case.

Changing number of the categories	Amount of the changed cell	Percentages of the changed cell
-2	10	% 1,51
-1	37	% 5,60
0	506	% 76,55
1	107	% 16,19
2	1	% 0,15

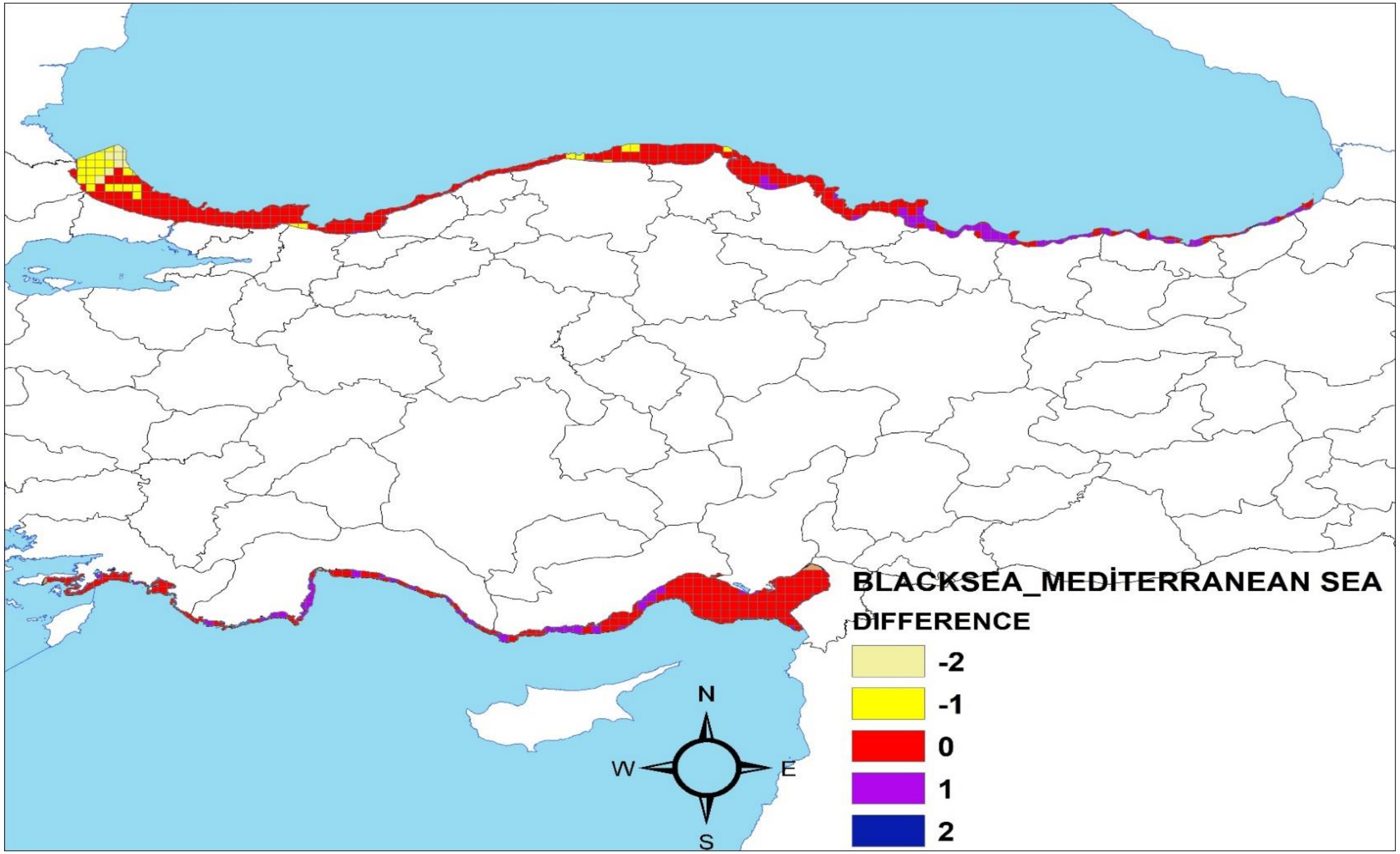


Figure 4.5. Categorical differences based on equal weighting case.

4.2. Results of the Second Discussion

4.2.1. Comparison of Black Sea Articles – Sensitivity to Wave Power Input Data

In order to have the second discussion, each wave power datasets obtained from the articles were put into the process to obtain suitability index of the regions. According to the results, suitability range of the regions were determined by considering different wave power datasets arising from the aforementioned articles. Results show that the analysis executed with the third article (Aydoĝan et al. 2013) have highest suitability index values since the wave power values of these article higher than the rest.

For the purpose of categorical comparison of the regions according to the articles, categories presented Figure 4.6, 4.7, 4.8 and 4.9 were sorted from 1 to 5 as seen in Table 4.6. When the analysis is executed with the wave power dataset of the second article, amount of the cell in “category-5” is relatively more than the rest. The reason why is that basically values of wave power dataset in the second article less than other which causes to many cells to be in the most suitable regions in terms of categorical perspective.

Suitability index range of the articles according to the map files are provided in Figure 4.6, Figure 4.7, Figure 4.8 and Figure 4.9. The gridded maps were categorized to five headings with natural breaking (Jenks) method mentioned previously. Although trends in the categorization of the suitability index, region by region by, is quite same with each other, values for the suitability index can be different as seen from Figure 4.6, 4.7, 4.8 and 4.9. The parameter causes to such a difference can be only wave power due to its importance factor. Therefore, it is obvious that using confidential dataset for wave power has an essential importance for the accuracy of the results.

Table.4.6. Categorical presentation of the regions to each article, Black Sea

Category No	SUITABILITY INDEX RANGE IN THE ARTICLE-1	PERCANTAGE OF CELL
1	0	42,93 %
2	0.01-0.53	10,42 %
3	0.54-0.59	15,14 %
4	0.60-0.64	23,82 %
5	0.65-0.77	7,69 %
Category No	**SUITABILITY INDEX RANGE IN THE ARTICLE-2**	**PERCANTAGE OF CELL**
1	0	42,93 %
2	0.01-0.40	2,98 %
3	0.41-0.47	15,14 %
4	0.48-0.52	17,62 %
5	0.53-0.58	21,34 %
Category No	**SUITABILITY INDEX RANGE IN THE ARTICLE-3**	**PERCANTAGE OF CELL**
1	0	42,93 %
2	0.01-0.51	10,42 %
3	0.52-0.61	21,09 %
4	0.62-0.72	19,35 %
5	0.73-0.86	6,20 %
Category No	**SUITABILITY INDEX RANGE IN THE ARTICLE-4**	**PERCANTAGE OF CELL**
1	0	42,93 %
2	0.01-0.44	14,89 %
3	0.45-0.51	17,12 %
4	0.52-0.59	20,84 %
5	0.60-0.71	4,22 %

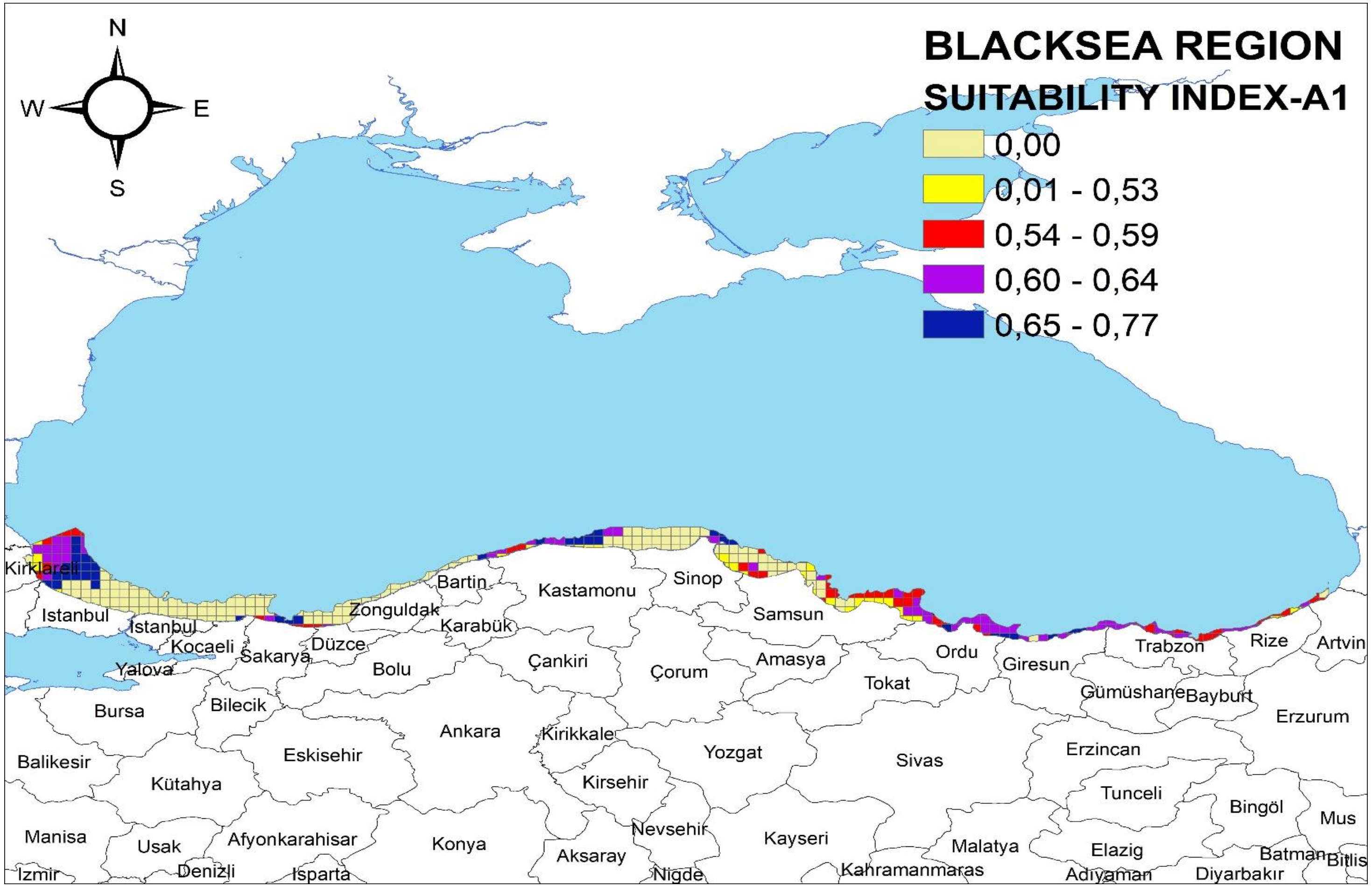


Figure 4.6. Categorization of suitability index in Black Sea with the wave power dataset of the first article (Akpınar et al. 2017)

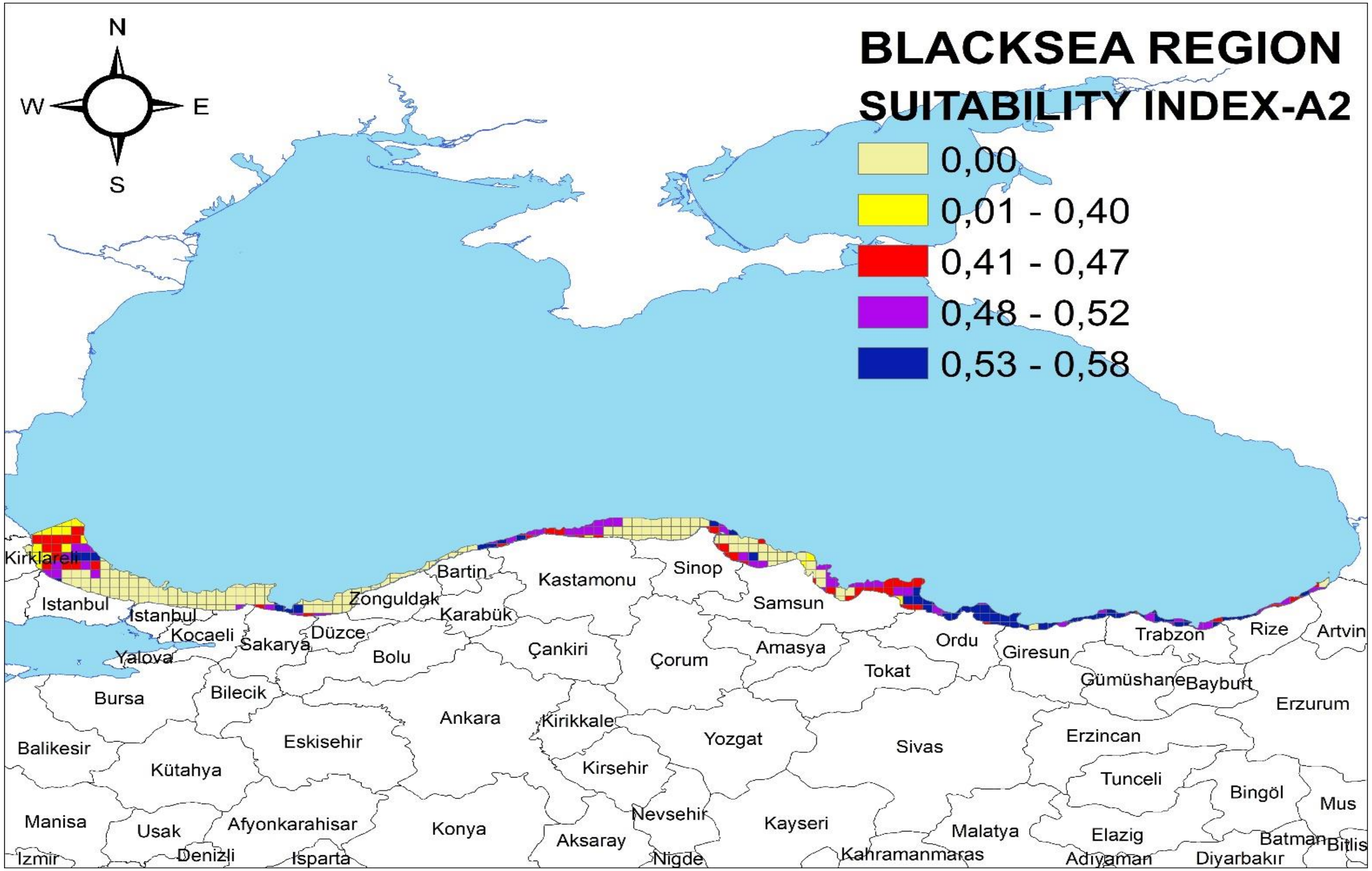


Figure 4.7. Categorization of suitability index in Black Sea with the wave power dataset of the second article (Akpinar and Kömürcü 2013).

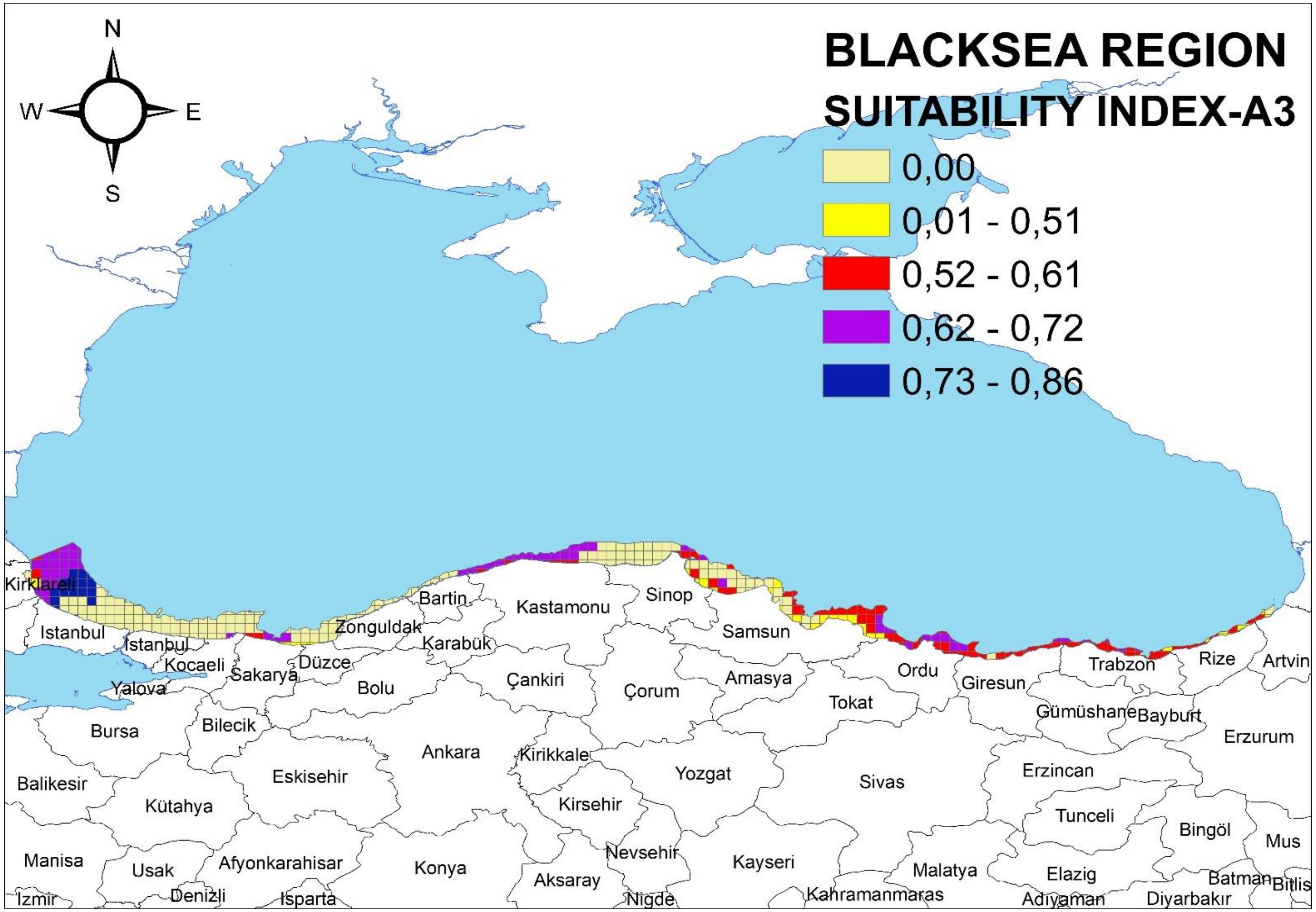


Figure 4.8. Categorization of suitability index in Black Sea with the wave power dataset of the third article (Aydoĝan et al. 2013).

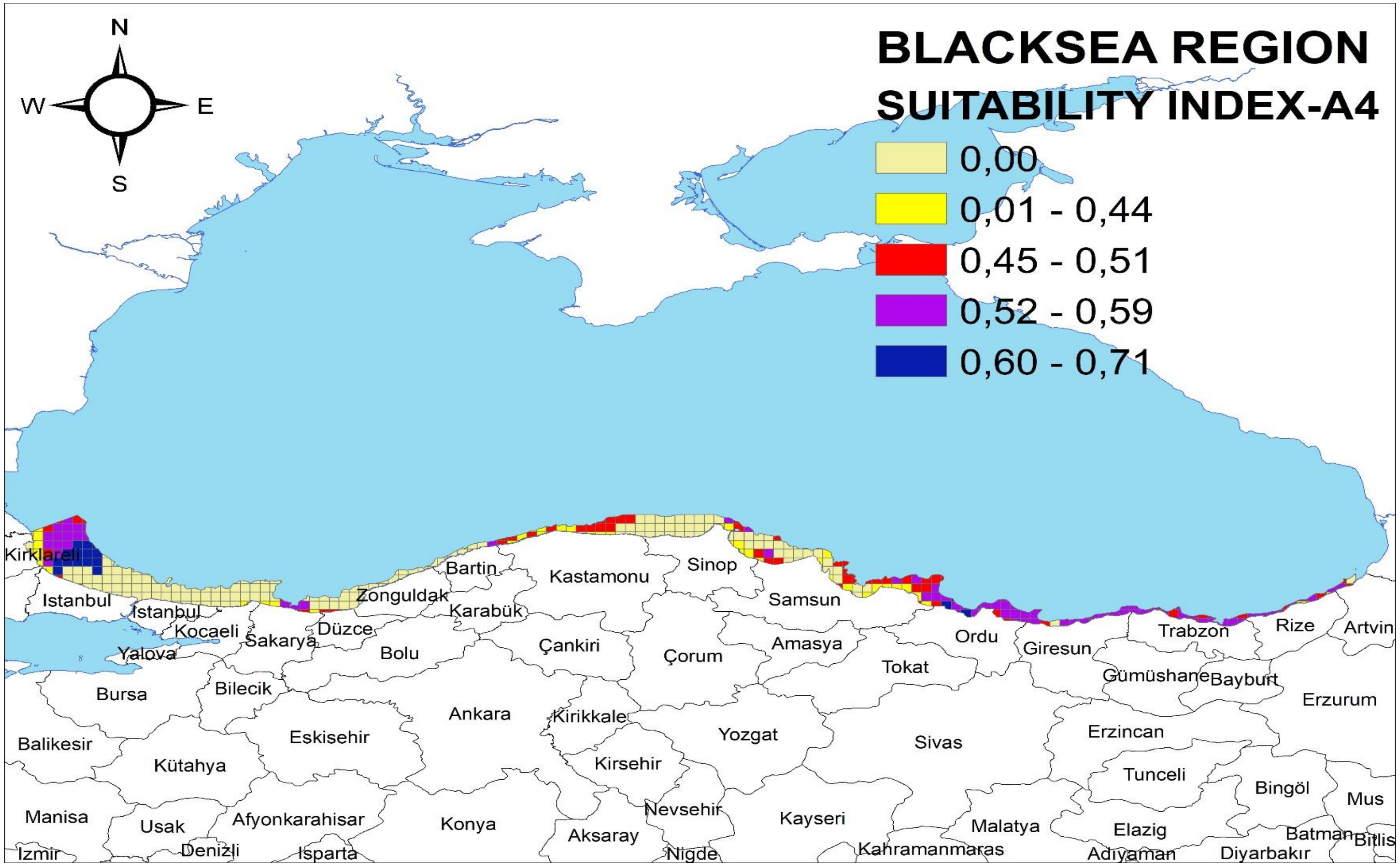


Figure 4.9. Categorization of suitability index in Black Sea with the wave power dataset of the fourth article (Rusu 2015)

According to these articles the most suitable regions are displayed in Figure 4.10 and to have more nested design it is seen that the highlighted cell in Figure 4.10 has the highest suitability index within this region.

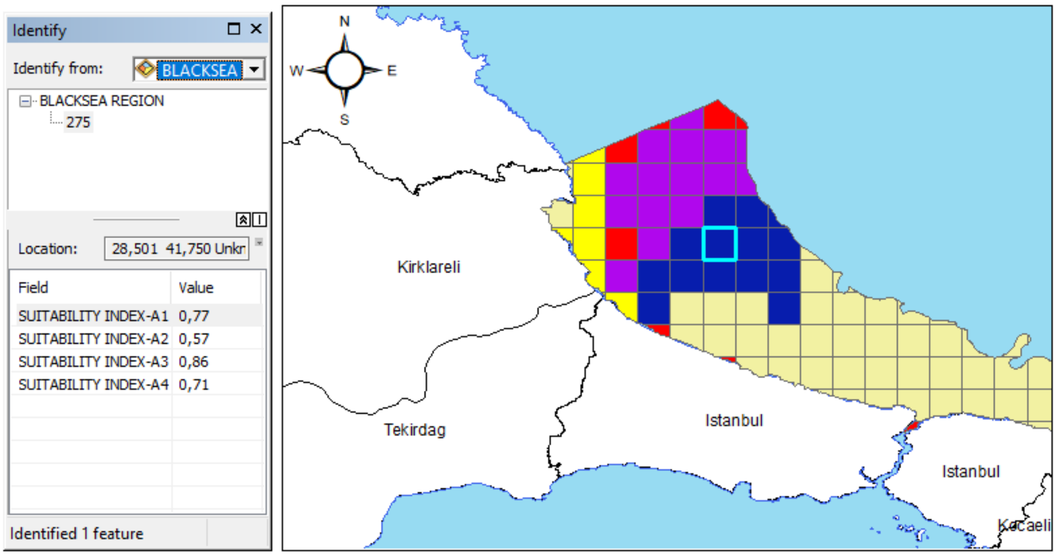


Figure 4.10. The most suitable cell

4.2.2. Comparison of Mediterranean Sea Articles – Sensitivity to Wave Power Input Data

The evaluation carried out for the Black Sea articles were applied to this region as well. It is seen that datasets acquired from the articles are in better correlation in Mediterranean Sea comparing with the Black Sea region as it is seen in Table 4.7. Categorization of the articles are presented in Figure 4.11, Figure 4.12, Figure 4.13 and Figure 4.14

Table 4.7. Categorical presentation of the regions to each article, Mediterranean Sea

Category No	SUITABILITY INDEX RANGE IN THE ARTICLE-1	PERCANTAGE OF CELL
1	0	55,81 %
2	0.01-0.37	8,53 %
3	0.38-0.44	11,63 %
4	0.45-0.50	15,50 %
5	0.51-0.59	8,53 %
Category No	**SUITABILITY INDEX RANGE IN THE ARTICLE-2**	**PERCANTAGE OF CELL**
1	0	55,81 %
2	0.01-0.38	7,75 %
3	0.39-0.45	18,22 %
4	0.46-0.51	12,79 %
5	0.52-0.59	5,43 %
Category No	**SUITABILITY INDEX RANGE IN THE ARTICLE-3**	**PERCANTAGE OF CELL**
1	0	55,81 %
2	0.01-0.39	11,24 %
3	0.40-0.46	17,83 %
4	0.47-0.53	10,47 %
5	0.54-0.62	4,65 %
Category No	**SUITABILITY INDEX RANGE IN THE ARTICLE-4**	**PERCANTAGE OF CELL**
1	0	55,81 %
2	0.01-0.38	10,47 %
3	0.39-0.45	17,05 %
4	0.46-0.52	12,40 %
5	0.53-0.59	4,26 %

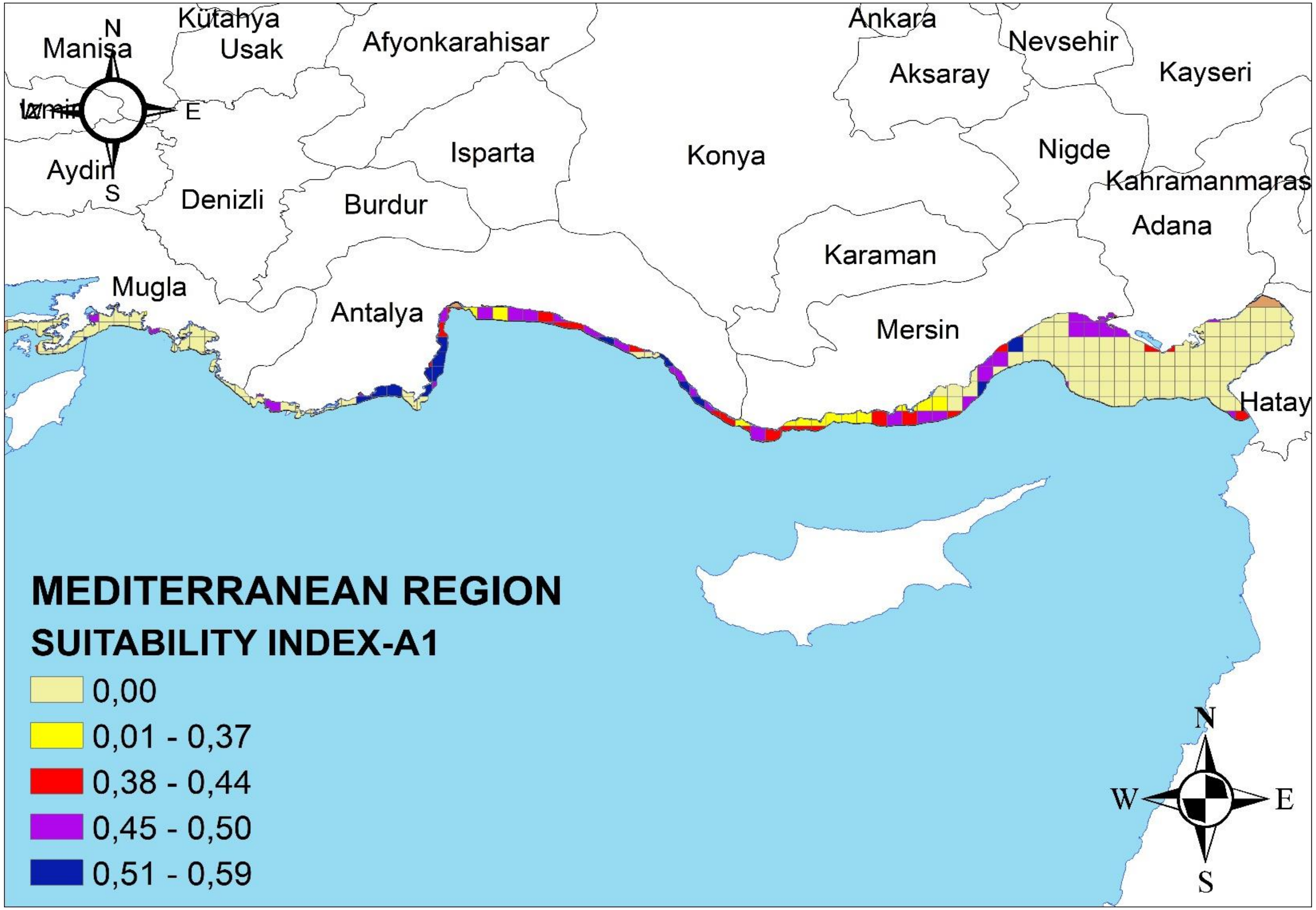


Figure 4.11. Categorization of suitability index in Mediterranean Sea with the wave power dataset of the first article (Besio et al. 2016).

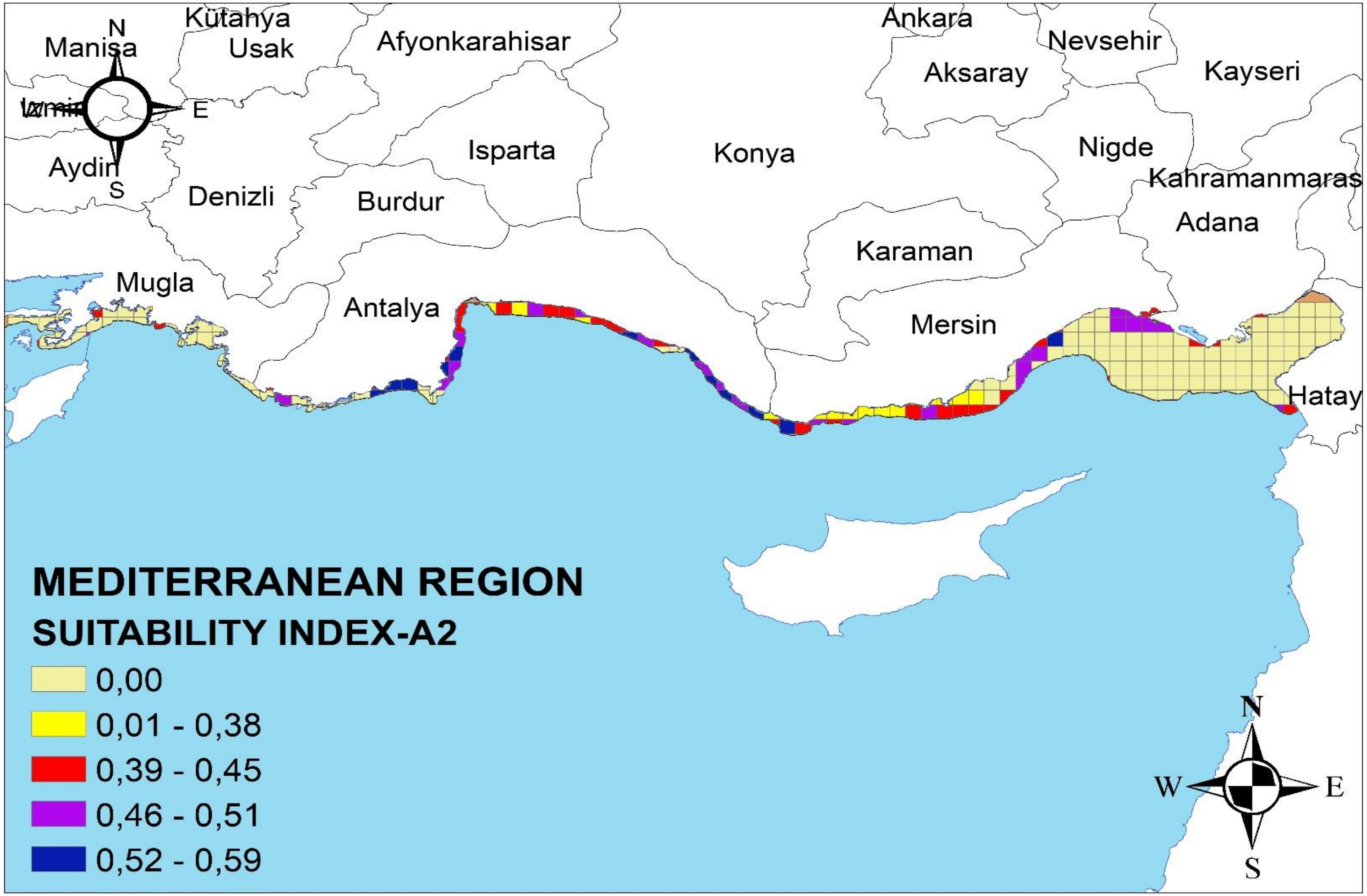


Figure 4.12. Categorization of suitability index in Mediterranean Sea with the wave power dataset of the second article (Liberti et al. 2013).

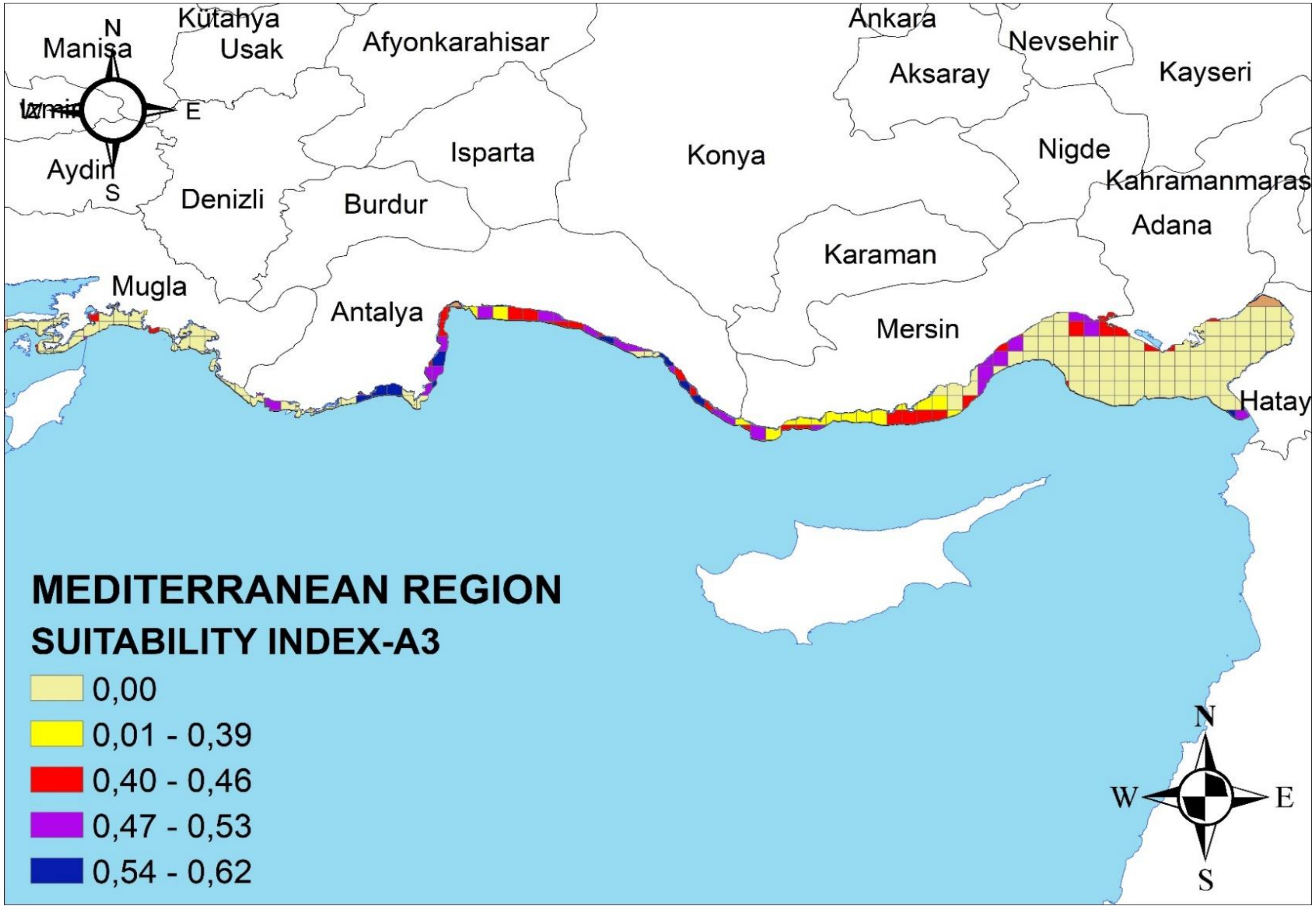


Figure 4.13. Categorization of suitability index in Mediterranean Sea with the wave power dataset of the third article (Zodiatis et al. 2014).

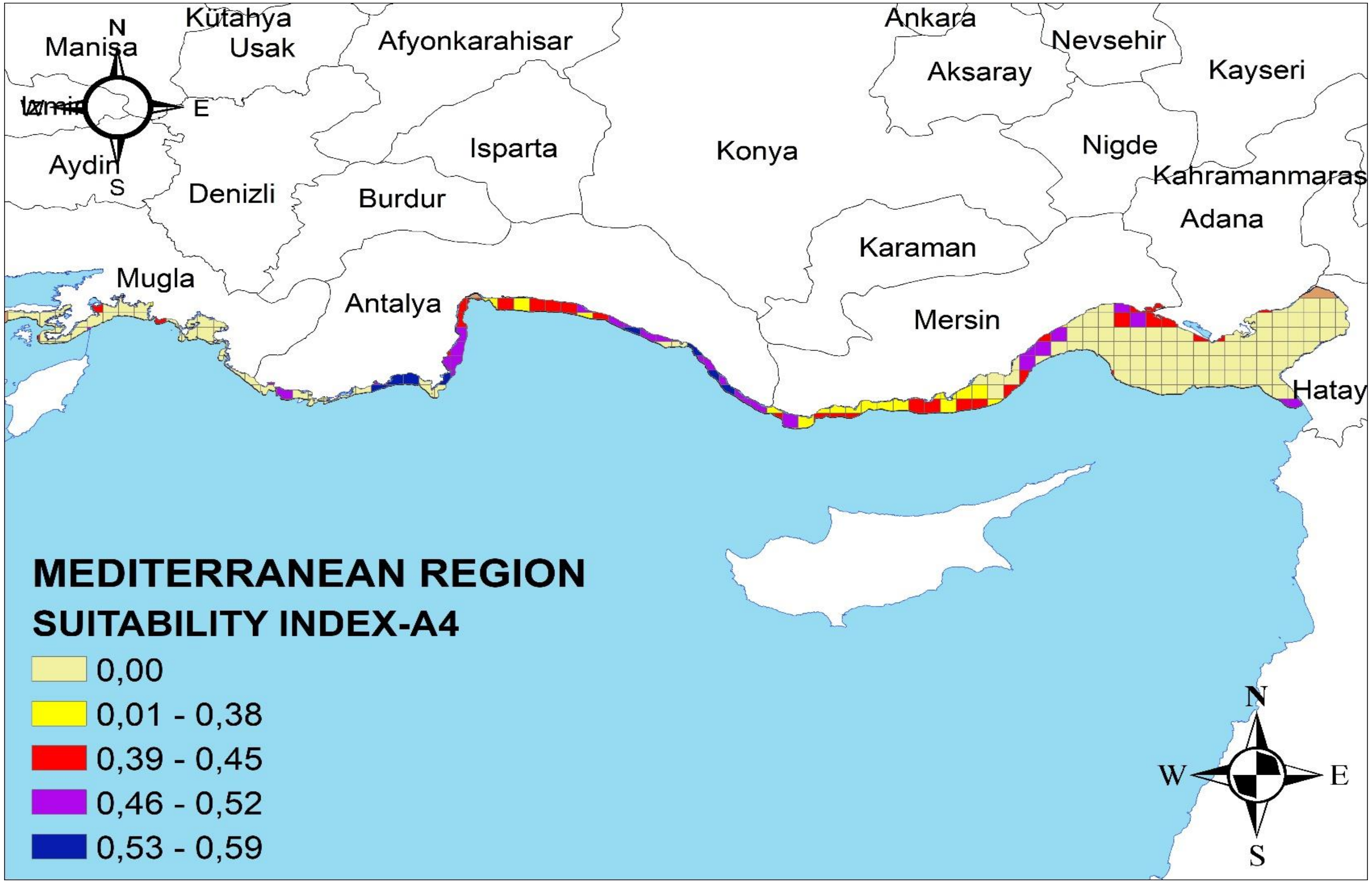


Figure 4.14. Categorization of suitability index in Mediterranean Sea with the wave power dataset of the fourth article (Ayat 2013).

CHAPTER 5

CONCLUSION

As a conclusion, the suitability index analysis were carried out combining with GIS for Black Sea and Mediterranean Sea coasts of Turkey. The results show that Western Black Sea region is the most suitable location for a potential wave energy conveter application considering technical, environmental and social dimensions of site selection problem. Although Eastern Black sea region has suitable sites considering many parameters used in site selection, the wave energy potential being low reduces the suitability of these regions. Similar conclusion can be drawn for Mediterranean coasts. Still, western coasts of Antalya Bay could be a candidate for potential applications for Mediterranean region.

In the presented study, the study region was bordered with continental shelf zone which is defined as the area between land and water where the water depth reaches to 200 m. As mentioned in the previous sections, the main reason why this restriction was applied to the study is that deploying WECs after 200 m of water depth is unfeasible because of the installation costs. Moreover, in the regard of technical consideration of WECs, it is more recommended to place these devices until the water depth of 200 m (Magagna and Uihlein 2015b). However, to expand the boundaries of the study region in Turkey, it is possible to make another assessment within the border of exclusive economic zone for the future studies.

Another remarkable issue with this study is that from the investor perspective, the selected best potential site still does not mean that it is feasible to deploy WECs when considering the investment costs and its payback period. Moreover, efficiency of WECs in other words capacity factor of wave power plants another aspect to take into consideration when talking in the feasibility of the deployment. Hence, it is obvious that feasibility studies considering economical aspects, technological features, etc would improve the decision making when coupled with the suitable sites determined with this study. Therefore, such a feasibility study could be a valuable further study for site selection of WECs.

This study shows that potential regions for the energy investments should be carried out using both GIS and MCDM in order to deal with the uncertainty of the factors and possible troubles might occur in the future. Moreover, the proposed study might be further developed including local stakeholders and policy makers, so that more comprehensive study can be executed to satisfy all the requirements suggested by every segment of the society. Taking into account the subjectivity and complication of the study, public surveys also can be implemented in order to specify social attitudes in the Turkish marine environment. Finally, the mathematical model introduced in this study, may also be suitable for other regions in conjuction with the small configurations. Additionally, implementation of different MCDM techniques and comparison of the results with this study might be a new topic for further research as well. Using different method should not mean the result given with this methods are wrong, it is just meaning that principle of different methods may differ from each other. So that it is worth to validate the results with different method and realize the different breakpoints of methods to give another recommendations for future energy planning.

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