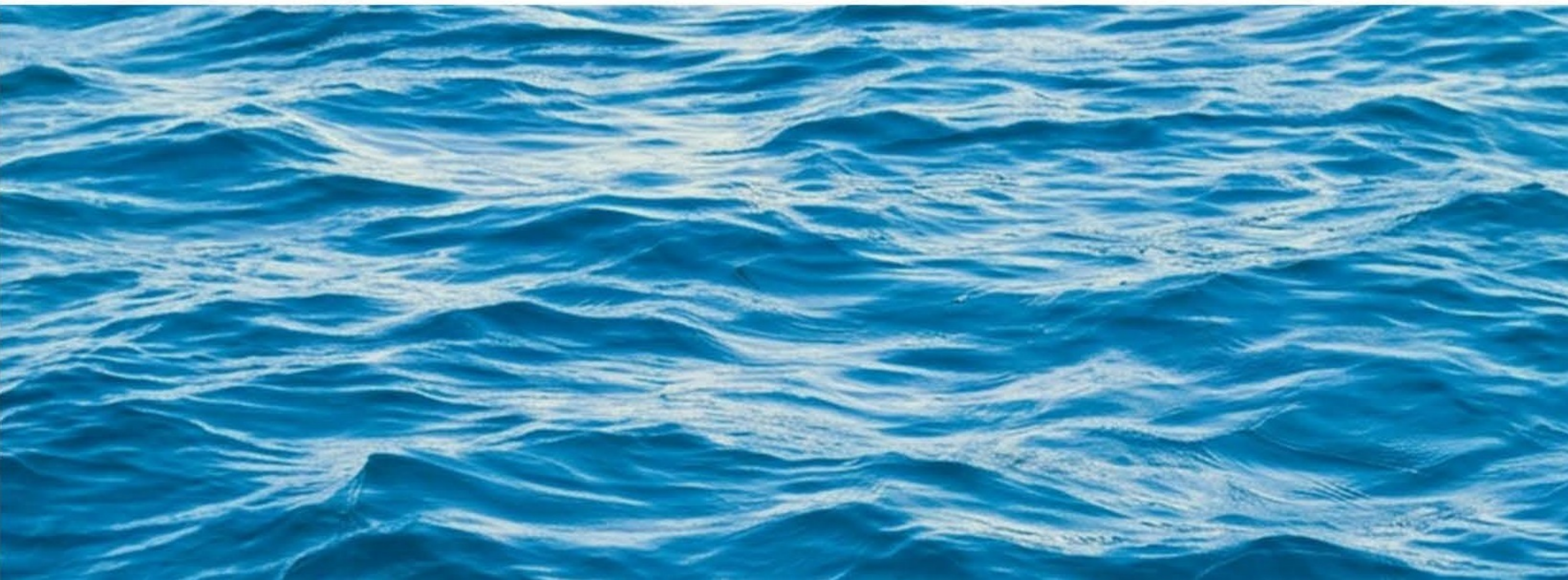
Monograph

THE BLUE ECONOMY:

CURRENT INDICATORS AND DEVELOPMENT TRENDS IN THE BLACK SEA

Mariia Slizhe, Mykola Berlinskyi, Youssef El Hadri



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Oceans are an important source of food, energy and other ecosystem services for humans. In recent decades, humanity has come to understand that the resources of the world's oceans are not unlimited and that they are suffering from excessive pressure from human activity. The Black Sea is a semi-enclosed sea that is very sensitive to anthropogenic and climatic influences. Intensive economic activity in the countries of Black Sea region by the end of the 20th century led to the loss of biodiversity and habitat degradation in the Black Sea, and marine and coastal ecosystems were on the brink of collapse. In the current situation, the transition to blue economy principles in marine resource management is the only way to stop destructive processes and preserve the Black Sea's natural potential. The monograph is devoted to solving the important scientific problem of sustainable use of marine resources in conditions of increasing human pressure and climate change.

The monograph is designed for a wide range of scientists in the field of oceanography, marine management and the blue economy, as well as students of higher education.

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Океани є важливим джерелом їжі, енергії та інших екосистемних послуг для людини. В останні десятиліття людство дійшло розуміння того, що ресурси світового океану не безмежні та що вони зазнають надмірного тиску з боку людини. Чорне море – це напівзамкнуте море, яке дуже чутливе до антропогенних та кліматичних впливів. Інтенсивна економічна діяльність у країнах Чорноморського регіону наприкінці XX століття призвела до втрати біорізноманіття та деградації середовища існування в Чорному морі, а морські та прибережні екосистеми опинилися на межі колапсу. У сучасній ситуації перехід до принципів блакитної економіки в управлінні морськими ресурсами є єдиним способом зупинити руйнівні процеси та зберегти природний потенціал Чорного моря. Монографія присвячена вирішенню важливої наукової проблеми сталого використання морських ресурсів в умовах зростаючого антропогенного тиску та зміни клімату.

Монографія розрахована на широке коло науковців у галузі океанології, управління морським середовищем та блакитної економіки, а також студентів вищих навчальних закладів.

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ABBREVIATIONS

CINEA – European Climate, Infrastructure and Environment Executive Agency
DBR – Danube Biosphere Reserve
ECMWF – European Centre for Medium-Range Weather Forecasts
EEZ – Exclusive Economic Zone
FAO – Food and Agriculture Organization
FSPO – floating production, storage and offloading
GDP – Gross domestic product
GRP – Gross Regional Product
GVA – gross value added
MAF – Multi-Actor Forum
OWT – offshore wind turbines
RED – Reverse Electrodialysis
PRO – Pressure Retarded Osmosis
SGP – Salinity gradient power
UNCTAD – United Nations Conference on Trade and Development
WRF – Weather Research and Forecasting

INTRODUCTION

It will soon be two decades since Gunter Pauli's work "Blue Economy: 10 Years, 100 Innovations, 100 Million Jobs" was published in 2010 as part of a report to the Club of Rome. The main idea of this work is the need to revise the general model of global economic development. The author proposes a new economic model, the so-called "blue" economy [1].

The term "blue economy" has broad application. In relation to the management and use of marine resources, it is understood as the set of economic sectors and associated policies that together determine whether ocean resource use is sustainable.

The primary goal of the blue economy is to determine how the economy should understand and better manage many aspects of ocean sustainability, from sustainable fisheries to ecosystem health and pollution.

Today, much research has been devoted to studying a wide range of issues of the blue economy. One of the research directions is the study of ocean stability in the context of food security, the development of sustainable fisheries, and the preservation of the health of marine and coastal ecosystems [2-6]. Also, questions of exchanging experience in marine resource management at the national and interstate levels, as well as between states and the private sector are examined in depth in a wide range of studies [7-12].

Based on the blue economy concept, special attention is also paid to issues of transition to new energy sources, within the framework of activities aimed at protecting the environment and combating climate change [13-18].

This study aims to examine the development trends of the blue economy in the Black Sea region with a focus on Ukraine, as well as the development prospects of some established and innovative sectors of the blue economy.

The analysis was conducted for the priority sectors of the blue economy in the Black Sea region countries, identified as a result of the DOORS project [19] study conducted in 2021-2024. To analyze the work of the marine living resources sector, data about capture production in the Black Sea, as well as aquaculture production in marine environments and aquatic processed production in the Black Sea countries, obtained from the FAO database [20] for 2010-2022 were used. The analysis of the marine and coastal tourism sector is based on annual statistics on import and export of services from the UNCTAD database [21] for 2010-2021 in Bulgaria, Georgia, Romania and Türkiye. The analysis of the number of bed-places and nights spent at tourist accommodation establishments was completed for Bulgaria, Romania and Türkiye, by data for 2012-2023 from the database Eurostat

[22] were used. In Bulgaria, statistics included – Severoiztochen and Yugoiztochen Planning Regions; in Romania – Sud-Est development region; in Türkiye – region İstanbul, provinces: Tekirdağ, Edirne, Kırklareli, Kocaeli, Sakarya, Düzce, Bolu, Yalova, Zonguldak, Karabük, Bartın, Kastamonu, Çankırı, Sinop, Trabzon, Ordu, Giresun, Rize, Artvin, Gümüşhane. The analysis of the number of bed-places and nights spent at tourist collective accommodation establishments in Georgia was based on National Statistics Office of Georgia data [23] in coastal regions Adjara, Guria and Samegrelo-Zemo Svaneti for 2010-2022; in Ukraine – based on data from the State Statistics Service of Ukraine [24] for Odesa, Mykolaiv, and Kherson regions in 2018-2020.

The study was conducted at the base of Oceanology and Marine Management Department of Odesa I.I. Mechnikov National University. Some of the results were obtained as part of a departmental scientific work "Assessment of risk factors for the sustainable use of marine resources of the Northwestern Black Sea" (without targeted funding).

The authors would like thank of the European Research Executive Agency for providing financial support of this research under Grant 101000518. This study is supported by ‘Developing Optimal and Open Research Support for the Black Sea (DOORS)’ project.

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Some of the research results presented in the monograph were published in peer-reviewed scientific journals [25-29].

CHAPTER 1: BLUE ECONOMY INDICATORS INTHE BLACK SEA

Today, EU maritime governance is guided by the principles of the blue economy. The general concept of the blue economy approach includes a number of principles related to the management of investments in human (intellectual) capital, rational use of natural resources and the creation of “smart” risk-resistant regional ecological and economic systems of a cluster type. It should be noted that the term “blue economy” has a wide application. In terms of the management and use of marine resources, it is understood as the set of economic sectors and associated policies that together determine whether the use of ocean resources is sustainable. The blue economy has various components, including established traditional ocean activities such as fisheries, tourism and maritime transport, as well as new activities such as marine (offshore) renewable energy, aquaculture, seabed mining and marine biotechnology. A number of services provided by ocean ecosystems for which markets do not exist also make significant contributions to economic and other human activities, namely coastal protection, waste management and biodiversity. In order to ensure a more coherent approach to marine resource management and coordination with other policy areas, the EU's Integrated Maritime Policy was developed in 2007 [30], which includes: blue growth, marine data and knowledge, marine spatial planning, integrated marine surveillance and sea basin strategies. Following this, the Marine Strategy Framework Directive was adopted in 2008 [31], which aim to achieve good environmental status by 2020 through introducing an ecosystem approach in marine resource management. In 2017, the European Blue Growth Strategy was adopted [32]. The goal of the strategy is to establish a match between ecosystem services and the needs of the blue industry through the use of appropriate policies. The blue economy is seen as a means of creating opportunities for new jobs and enterprises.

In the Black Sea countries, the blue economy generated €2 billion in gross value added (GVA) and 0.16 million jobs in 2019. The main sectors were coastal tourism, providing 0.09 million jobs and €1 billion in GVA, shipbuilding and repair, and port activities [33].

In Bulgaria, several blue economy sectors, including coastal and marine tourism, fisheries and aquaculture, shipping, port activities, shipbuilding, and oil and gas extraction, generated about €995 million in GVA in 2018, which is approximately 2% of the national GVA of all economic sectors and providing 3.4% of all jobs [34]. The main guiding documents are: Marine Spatial Planning Directive, Marine Strategy Framework Directive, Water Framework Directive, Environmental Impact Assessment, Habitats and Birds Directive. These EU directives are reflected in the relevant national legislation of Bulgaria.

Georgia's maritime economic complex plays a key role in the Georgian economy. Within the framework of the European Neighbourhood Policy, the Government of Georgia has assumed responsibility for environmental protection, which is reflected in the Georgian legislation in the water sector (Law of Georgia "On Water" No. 936-IS of 1997) [35], which is brought into line with EU requirements. The national program for harmonization of Georgian legislation with EU legislation provides for the adoption of specific EU directives in the water sector, which is currently considered a priority [36].

In 2021, Romania's blue economy sectors currently employ over 58000 people and generate around €1 billion in GVA. The Blue Economy has a relatively small share in the Romanian economy, employing 0.7 % of the total working population and generating 0.5 % of the national GVA [37].

In Türkiye, the blue economy accounts for 1.1 % of the national GVA and 1.4 % of jobs in the country, according to 2018 data [38].

Today, Ukraine attaches great importance to ensuring security and stabilizing the situation in the Black Sea region, guided by its national interests, the foundations and principles of its foreign policy [39-40]. The development of the blue economy in Ukraine will be examined in more detail in Chapter 2.

Today the main task for Black Sea countries is identification of blue economy sectors with a significant potential for growth for consideration by policy makers for the development of relevant policy instruments and the set-up of national funding programmes.

1.1 Marine living resources

There are 184 species and subspecies of fish in the Black Sea, of which 144 are exclusively marine species, 24 are anadromous or partially anadromous, and 16 are freshwater species. Of the total number of fish, about 20% are used as commercial fisheries. Various researchers estimated the initial stocks and production of fish in the Black Sea at 0.5-5.7 million tons and 0.25-2.9 million tons, respectively. According to FAO, the most capture production in the Black Sea in 2010-2022 amounted to European anchovy (*Engraulis encrasicolus*). The main catch is carried out by Türkiye (the largest annual catch was 233.08 thousand tons in 2019) and Georgia (99.29 thousand tons in 2017). The second by the most capture production is European sprat (*Sprattus sprattus*). The main producing countries are Türkiye (the largest annual catch was 86.68 thousand tons in 2011) and Ukraine (24.65 thousand tons in 2010). Third in terms of annual production – Striped venus (*Chamelea gallina*), the largest catch of which is carried out by Türkiye (61.23 thousand tons in 2012). The catch volume of these three types of marine living resources in the Black Sea in 2021 amounted to 306.6 thousand tons. For comparison, in 2021, the catch volume of the three most harvested species (sprat, herring and flounder) by EU Member States' fleets in the Baltic Sea amounted to 439.98 thousand tons [41].

According to data for 2019, the total catch of marine living resources in the Black Sea amounted to 552.76 thousand tons. In the same 2019, in the Mediterranean Sea 1.18 million tons of marine living resources were harvested. The leading countries in production are: Turkey (431.57 thousand tons), Italy (174.69 thousand tons), Tunisia (107.48 thousand tons) and Algeria (100.15 thousand tons).

It should be noted that the main species caught (average annual catch) in the Black Sea include:

- Bulgaria: Asian rapa whelk (*Rapana venosa*) – 3.64 thousand tons, European sprat (*Sprattus sprattus*) – 3.08 thousand tons, Red mullet (*Mullus barbatus*) – 379 tons, Sand gaper (*Mya arenaria*) – 328 tons, European anchovy (*Engraulis encrasicolus*) – 182 tons.

- Georgia: European anchovy (*Engraulis encrasicolus*) – 51,0 thousand tons, Mediterranean horse mackerel (*Trachurus mediterraneus*) – 270 tons, Asian rapa whelk (*Rapana venosa*) – 250 tons.

- Romania: Asian rapa whelk (*Rapana venosa*) – 3.67 thousand tons, Mediterranean mussel (*Mytilus galloprovincialis*) – 100 tons, European sprat (*Sprattus sprattus*) and European anchovy (*Engraulis encrasicolus*) – 60 tons.

- Türkiye: European anchovy (*Engraulis encrasicolus*) – 138.40 thousand tons, European sprat (*Sprattus sprattus*) – 37.90 thousand tons, Striped venus (*Chamelea gallina*) – 31.50 thousand tons, Mediterranean horse mackerel (*Trachurus mediterraneus*) – 11.40 thousand tons, Whiting (*Merlangius merlangus*) – 8.80 thousand tons.

- Ukraine: European sprat (*Sprattus sprattus*) – 7.12 thousand tons, European anchovy (*Engraulis encrasicolus*) – 6.35 thousand tons, Asian rapa whelk (*Rapana venosa*) – 2.49 thousand tons, Big-scale sand smelt (*Atherina boyeri*) – 640 tons, Gobies nei (*Gobiidae*) – 360 tons.

Türkiye is the leading producer of marine living resources in the Black Sea, with its catch accounting for 59.7 % of the total production (Fig. 1.1). In 2022, Türkiye extracted 193.39 thousand tons of marine living resources in the Black Sea. Turkey's fishing industry employs more than 30000 people [42]. The fishing fleet consists of 14500 vessels (large and small). For comparison, it should be noted that the fishing fleet of EU countries fishing in the Baltic Sea in 2021 amounted to 4300 vessels [43], with the highest number of large vessels (≥ 12 m) coming from Sweden (470 vessels), Denmark (180 vessels) and Poland (150 vessels). The average annual catch volume by Türkiye in 2010-2022 is 248.84 thousand tons. The years with the largest catch were 2011 (365.46 thousand tons), 2019 (346.15 thousand tons) and 2015 (317.37 thousand tons). Fish is exported mainly into European countries – the Netherlands, England and Norway, to some African countries such as Ghana and Ivory Coast, and to South-Eastern countries such as Singapore and Thailand [44].

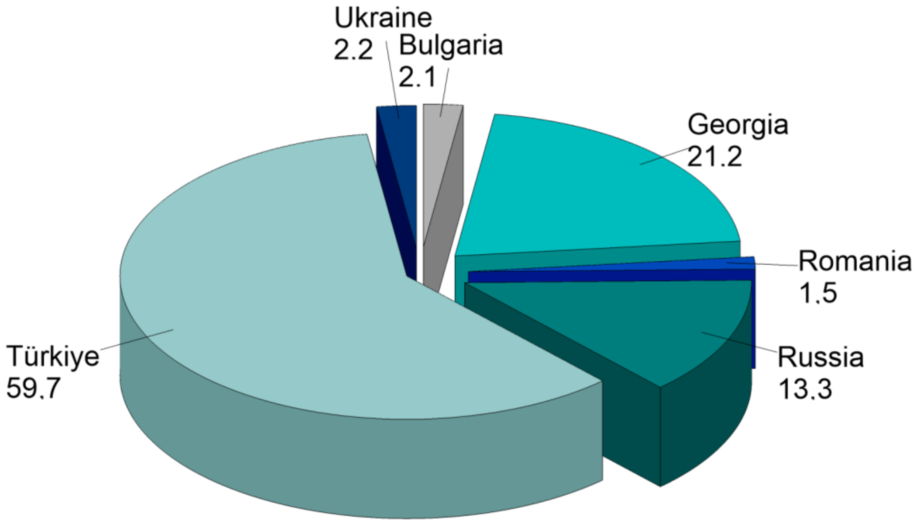

Fig. 1.1 Capture production (%) of marine living resources in the Black Sea in 2018-2022

Georgia, despite the fact that fishing is a growing industry and its share in GDP as of the third quarter of 2018 was less than 1 %, in terms of the marine living resources extraction, it ranks second among the countries of the Black Sea basin, extracting 21.2% (Fig. 1.1) from the total catch. In 2022, Georgia caught 68.48 thousand tons of living marine resources. Overall, in 2010-2022, the average annual catch is 51.48 thousand tons. It should be noted that the Georgian fishing fleet consists of about 30 vessels, most of which are trawlers and seiners. The fishing sector employs approximately 500 people. However, most of the vessels are outdated and do not correspond to the modern requirements of the fishing industry [45]. In 2017, Georgia increased the extraction of marine living resources by 3.65 times, from an average annual value of 23.25 thousand tons (in 2010-2016) to 84.42 thousand tons (in 2017-2022) (Tab. 1.1). The maximum amount of marine living resources extracted by Georgia was recorded in 2017 and amounted to 99.61

thousand tons (Fig. 1.2, Table A.1). From 2010 to the present, fish exports from Georgia are mainly directed to Türkiye, Azerbaijan and Armenia [36]. It should be added that in 2017, the EU included Georgia in the list of third countries from which the import of Black Sea fish and fish products to the European market is permitted.

Table 1.1 Indicators of marine living resources sector
in 2010-2016 (A) vs 2017-2022 (B)

Indicator, 1000 tons of live weight	Bulgaria		Georgia		Romania		Türkiye		Ukraine	
	A	B	A	B	A	B	A	B	A	B
Capture production	8.7	8.0	23.2	84.4	2.4	6.4	266.0	228.8	27.1	7.8
Aquatic processed production	18.1	21.4	-	-	17.6	20.8	119.4	241.3	111.1	58.3

In 2018-2022, Ukraine's share amounted to 2.2 % of the total volume of marine living resources extracted in the Black Sea. Before the start of hostilities in the northwestern part of the Black Sea, Ukraine ranked fourth in the catch of living marine resources in the Black Sea. A significant decrease in the catch was noted in 2014 after the annexation of Crimea, when the catch decreased by 9.7 times. In 2013, the largest fishing centers in Ukraine were located in Sevastopol, Kerch, Odessa, Berdyansk, and in 2014 the situation changed dramatically [46]. As a result of the annexation of Crimea, Ukraine lost a significant part of its fisheries. Until 2014, Crimea accounted for more than 60 % of aquatic biological resources production. After the annexation, 108 vessels remained in Crimea (20 port vessels, 11 state and 60 private fishing vessels, 17 vessels belonging to territorial bodies of the State Fisheries Agency).

In 2022, Ukraine extracted 164 tons of living marine resources. In 2010-2022 the average annual production was 18.19 thousand tons. In addition to the above, to reduce fishing in the high seas and the inactivity of fishing in the exclusive economic zones of other states the main influence is that Today in Ukraine the fleet resource is morally and materially obsolete, the ship repair and port infrastructure is outdated, the technologies for searching and catching fish on domestic vessels are not competitive, there is a low level of state investment in the fixed capital of domestic fisheries enterprises [47].

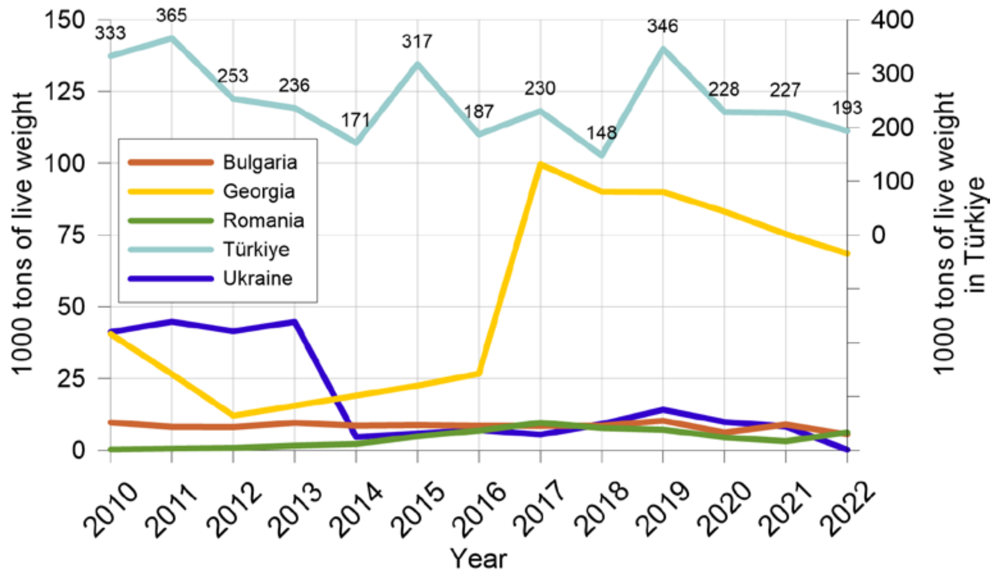

Fig. 1.2 Capture production of marine living resources (thousand tons of live weight)

The share of the volume of marine living resources extraction in the Black Sea by Bulgaria and Romania is 2.1 and 1.5 %, respectively. The average annual catch for the study period was 4.25 thousand tons and 8.39 thousand tons, respectively. In Romania, from 2010 to 2022, there was an increase in the extraction of living marine resources by 26.7 times, while for Bulgaria, there was a decrease in the amount of extraction by about 1.2 times. This led to the fact that in 2022, Romania caught 6.18 thousand tons of marine living marine resources, and Bulgaria – 5.50 thousand tons.

An analysis of the aquatic processed production from 2010 to 2021 showed that Türkiye annually processes 170.2 thousand tons of live weight of aquatic products. In recent years, it has been possible to increase processing by 3.3 times compared to 2010. Ukraine, on average, annually processes 89.12 thousand tons of aquatic products. Over the period from 2010 to 2021, there was a decrease in the volume of processing in Ukraine by 3.5 times. In Bulgaria and Romania, the average annual volumes of processed aquatic products are 19.47 thousand and 18.92 thousand tons, respectively. At the same time, there is an increase in this indicator by 1.4 and 1.2 times, respectively.

Marine aquaculture. Today, mariculture is one of the most promising innovative sectors of the Blue Economy. According to FAO data for 2018-2022 on mariculture production in the Black Sea, the total annual production volume by Bulgaria, Georgia, Romania and Ukraine is 2.34 thousand tons (Table A.2). Türkiye is one of the leaders in mariculture production, but mainly places its production facilities on the Mediterranean and Aegean coasts. For comparison, in

2019 in the Mediterranean Sea, 882.11 thousand tons of mariculture for US$3.48 billion was grown [48]. The main producing countries are: Egypt (272.22 thousand tons for US$773.35 million), Turkey (255.06 thousand tons for US$1.02 billion), Greece (126.38 thousand tons for US$560.9 million) and Italy (106.63 thousand tons for US$360.38 million).

FAO data about marine aquaculture production show that in Bulgaria, in the period 2010-2022 an average of 2.22 thousand tons of aquatic products was produced annually for US$2.17 million (Table A.3). The main species grown in 2010-2022 was the Mediterranean mussel (*Mytilus galloprovincialis*). In 2021-2022, Bulgaria began to grow in small volumes of 2.5-3.5 tons per year the Pacific cupped oyster (*Crassostrea gigas*). The highest production rate was observed in 2016 (3.93 thousand tons of Mediterranean mussel (*Mytilus galloprovincialis*) for US$3.25 million.

Georgia in 2014-2018 annually produced an average of 56.0 tons of live weight of mariculture, for US$200 thousand. The mariculture sector produced: 20.0 tons of Marine fishes nei (*Osteichthyes*) annually for the amount offor US$82 thousand, in 2014-2015, and 80 tons of live weight Rainbow trout (*Oncorhynchus mykiss*) annually for the amount of for US$280 thousand, in 2016-2018. It should be noted that positive changes in the aquaculture sector in Georgia began to be observed with starting from 2021. This is primarily due to the development of the draft Law on Aquaculture [49].

In Romania, according to data for 2011-2016, an average of 27 tons of mariculture was grown annually, an average for US$90.5 thousand. The main species grown are Mediterranean mussel (*Mytilus galloprovincialis*), the average annual production volume of which is 17.8 tons for US$29.5 thousand, Turbot (*Psetta maxima*) – 18.5 tons for US$120.9 thousand, and in small quantities Pacific cupped oyster (*Crassostrea gigas*) and Marine fishes nei (*Osteichthyes*).

Türkiye is the most developed country in the Black Sea region in the field of aquaculture cultivation, where, according to FAO, 22 types of mariculture are grown. In general, in Türkiye, including the Mediterranean and Aegean coasts, an average of 187.2 thousand tons of mariculture is produced annually, for US$936.0 million. In 2010-2022, there has been an annual increase in manufactured products. In 2022, on farms 368.7 thousand tons of live weight of mariculture were grown for US$2.06 billion. The main production species is European seabass (*Dicentrarchus labrax*), the average annual production volume of which is 98.2 thousand tons of live weight for US$502.61 million. In second place is the Gilthead seabream (*Sparus aurata*) – 70.2 thousand tons for US$329.81 million.

In third place is the Rainbow trout (*Oncorhynchus mykiss*) – 12.1 thousand tons for US$47.36 million.

In Ukraine, according to FAO data for 2010-2015, on average 78.1 tons of live weight of mariculture was grown annually for a total of US$93.7 thousand. This indicator was formed due to the cultivation Mediterranean mussel (*Mytilus galloprovincialis*). It should be added that in Ukraine, aquaculture was also grown in brackish water (Black Sea limans) with an average annual production volume of 647.3 tons for US$1.7 million. The main species grown in brackish water was So-iuy mullet (*Mugil soiuy*), whose average annual production was 634 tons for US$1.65 million.

It should also be added that in recent years, mariculture has been cultivated in artificial reservoirs with sea water in Bulgaria and Romania. Production volumes in 2022 were 22.5 and 19 tons of live weight, worth US$421.1 and US$275.5 thousand, respectively.

1.2 Marine and coastal tourism

The tourism sector is one of the most promising sectors of the Blue Economy of the Black Sea countries. Bulgaria annually in 2013-2021 provides export of services (providing tourism services to foreign guests and tourists from other countries) in the field of marine and coastal tourism for US$1.23 billion (Table B.1-B.2). The highest values were recorded in 2018 (US$1.59 billion), the lowest in 2020 (US$550.11 million). At the same time, on average, Bulgaria annually receives imports of services (provision of services by non-resident producers to residents of the country) of marine and coastal tourism for US$335.8 million. Net exports of services decreased from US$998 million in current prices in 2013-2016 to US$816 million in 2017-2021 (Fig. 1.3).

In Georgia, the average annual export of marine and coastal tourism services of amounts to US$701.8 million. The highest values were recorded in 2019 – US$1.18 billion. It should be noted that the COVID-19 pandemic and the resulting lockdowns have had a significant impact on the tourism industry in the Black Sea region of Georgia, in 2020, the amount received from the provision of coastal and marine tourism services was on 84 % lower than the amount received in 2019, and amounted to US$189.32 million. The average annual import of marine tourism services in Georgia is US$15.8 million. Net exports of tourism services increased in 2017-2021 to US$765 million (Fig. 1.3), which is US$178 million higher than the values for the period 2013-2016 (Tab. 1.2).

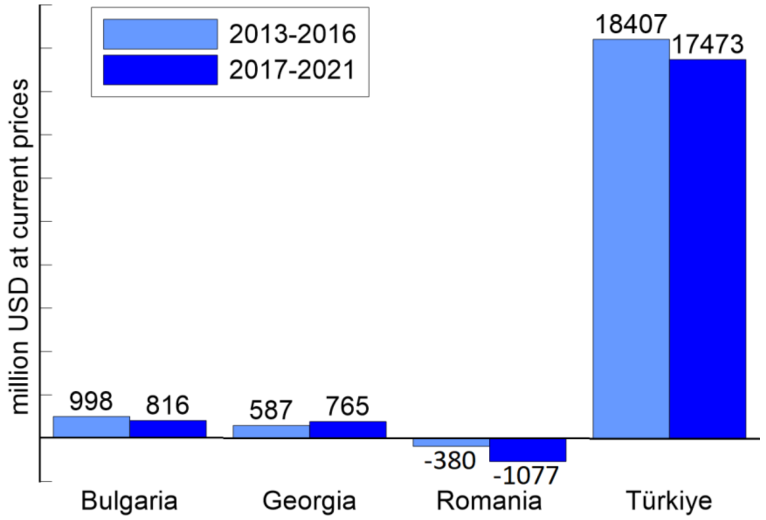

Fig. 1.3 Average net exports of coastal and marine tourism services for 2013-2016 and 2017-2021 (US$ million at current prices)

In Romania, in all years from 2013 to 2021, imports of marine and coastal tourism services exceeded exports. In 2017-2022, compared to 2010-2016, the volumes of export and import of tourism services increased by 2.8 times (Tab. 1.2) and amounted to US$642.8 million and US$1719.4 million, respectively. Net exports (Fig. 1.3) decreased from US$-380 million in 2013-2016 to US$-1.08 billion in 2017-2021. On average, Romania annually exports services worth US$459.0 million, while imports of services amount to US$1.23 billion. It should be noted that the amount of export and import of marine and coastal tourism services increases annually. The highest values of services exports were recorded in 2021 (US$805.58 million). The highest amount of imports of tourism services in Romania was recorded in 2019 (US$2.17 billion). The decrease in the amount of services exports due to COVID-19 lockdowns was 58.9 %, and the import of services was 53.3 %.

Table 1.2 Indicators of marine and coastal tourism sector in 2010-2016 (A) vs 2017-2022 (B)

Indicator, US$ million at current prices	Bulgaria		Georgia		Romania		Türkiye	
	A	B	A	B	A	B	A	B
Export	1294.8	1182.5	597.3	785.4	229.2	642.8	21400.9	19690.7
Import	297.3	366.5	10.5	20.0	609.7	1719.4	2993.6	2218.1

The highest indicators in the marine and coastal tourism sector among the Black Sea countries in 2013-2021 are observed in Türkiye, due to its geographical location and, accordingly, the inclusion in the country's Blue Economy of the coastal regions of the Mediterranean and Aegean Sea, which are the most attractive for tourists due to their climatic and hydrological conditions. On average, Türkiye's coastal tourism exports generate US$20.45 billion in current prices annually. The highest values were recorded in 2019, when services exports amounted to US$27.88 billion. Türkiye's average annual import of marine and coastal tourism services is US$2.56 billion. In 2020, as in other countries of the Black Sea basin, there was a decrease in the amount of exports and imports of tourism services by 64.8% and 75.3%, respectively. Net exports of services averaged US$17.47 billion in 2017-2021, down US$934 million from previous years (Fig. 1.3).

For comparison, in Italy, one of the leaders in the tourism business in Southern Europe, in 2017-2021, the annual import of marine and coastal tourism services amounted to US$12.57 billion, and the export of services amounted to US$27.78 billion. Net export amounted to US$15.21 billion annually.

In Bulgaria, the number of bed-places at tourist accommodation establishments in coastal Severoiztochen and Yugoiztochen Planning Regions on average is 230.58 thousand bed-places. In 2020, there was a decrease to 186.36 thousand bed-places, in 2023 the number reached pre-pandemic levels and amounted to 250.60 thousand bed-places. Quantity of nights, spent at tourist accommodation establishments, on average for 2013-2023 is 15.18 million nights per year. It should be noted that in 2019 the number of nights, spent at tourist accommodation establishments were 18.45 million, however in 2020 the COVID-19 pandemic lockdowns led to this value falling to 6.78 million. In subsequent years, an increase in this value is noted, in 2023 it reached 16.7 million.

The coastal region of Romania includes the South-East Development Region, with an average number of bed-places at tourist accommodation establishments is 111.06 thousand bed-places. In 2013-2023, the smallest number of bed-places at tourist accommodation establishments was registered in 2017 (99.21 thousand bed-places), after which an increase in registered bed-places was noted, amounting to 137.42 thousand bed-places in 2023. On average, 5.31 million nights, spent at tourist accommodation establishments are registered in the coastal areas of Romania per year. The highest values were recorded in 2019 (6.29 million nights). In 2020, as a result of the COVID-19 pandemic-related lockdowns, the number of registered nights, spent at tourist accommodation establishments decreased to 4.08 million units. In 2023, this value reached pre-pandemic levels and amounted to 6.14 million units.

As stated above, the Black Sea coastal regions of Türkiye include: İstanbul region and provinces Tekirdağ, Edirne, Kırklareli, Kocaeli, Sakarya, Düzce, Bolu, Yalova, Zonguldak, Karabük, Bartın, Kastamonu, Çankırı, Sinop, Trabzon, Ordu, Giresun, Rize, Artvin, Gümüşhane, where the number of registered bed-places at tourist accommodation establishments is close to 14.5 million units. The average annual number of registered nights, spent at tourist accommodation establishments in 2013-2022 is 28.86 million. The highest values were recorded in 2022 and amounted to 58.43 million nights.

Available data on tourism sector in the coastal Black Sea regions of Ukraine cover 2018-2020 and include data for Odesa, Mykolaiv, and Kherson regions. The average number of registered bed-places at tourist accommodation establishments is 52.02 thousand units. The highest values were recorded in 2018 (55.63 thousand bed-places). The number of nights, spent at tourist accommodation establishments averaged 2.03 million nights annually.

1.3 Port activities

The Black Sea region is located at the crossroads of trade routes from all directions leading to the countries of Europe. According to data for the last 5 years, the top ten Black Sea ports in terms of annual cargo handling (million tons) include: Constanta – 90.0, Pivdenny – 53.5, Mykolaiv – 29.9, Chornomorsk – 25.6, Odesa – 22.6, Samsun – 14.2, Varna – 7.7 and Poti – 7.0.

On average, 148.19 million tons of cargo was handled annually in the ports of Ukraine in 2017-2021 (Fig. 1.4). In Romania, the largest sea port Constanta and Danube River Ports Medgidia and Galati, which although not located directly on the Black Sea, have access to it via the Danube and are important for Black Sea trade, handle a total of 104.29 million tons of cargo annually. In the Black Sea ports of Türkiye in 2012-2022, on average 40.15 million tons of cargo are handled annually. The three largest ports in Bulgaria – Varna, Balchiuk and Burgas – handle a total of 14.68 million tons of cargo annually. In Georgia, according to data on cargo handling in the ports of Poti and Batumi, an average of 7.7 million tons is handled annually.

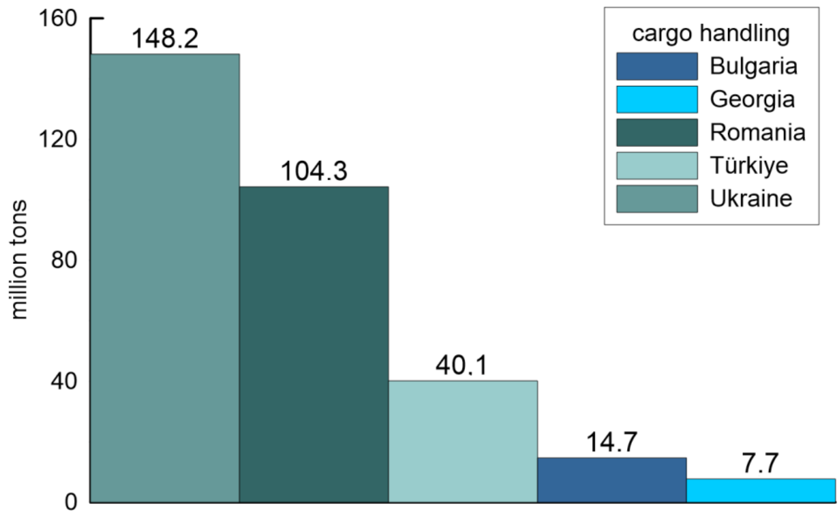

Fig. 1.4 Average annual cargo handling (million tons) in the seaports of Black Sea

An analysis of exports and imports of port services, and also related infrastructure services and logistical services, showed that on average, in 2010-2022, in the countries of the Black Sea basin, there is an excess of service exports over service imports (Table C.1-C.3). The amount of exports of services exceeds the amount of imports of services in Georgia (71.3 times), Türkiye (10 times), Ukraine (5.8 times), Romania (1.9 times) and Bulgaria (1.2 times).

In Bulgaria, in 2010-2015, imports of port services (import of services refers to the purchase of services by a resident from a non-resident regardless of the place of service delivery) exceeded exports by 3.4 times and amounted to an average of US$31.2 million in current prices annually. In 2016, these values became closer in magnitude and amounted to US$28.9 and US$30.5 million, respectively. In 2016-2021, exports of port services exceeded imports by an average of 2.5 times. It should be noted that in the period from 2015 to 2021, there was a decrease in the amount of imports of port services from US$45.7 million in 2015 to US$8.4 million in 2021. At the same time, in 2013-2017, there was an increase in the amount of port services exports from US$8.5 million in 2013 to US$98.3 million in 2017. After which the amount of exports decreased until 2021, when it amounted to US$37.5 million. In 2022, the trend changed and imports of port services exceeded exports by 1.4 times and amounted to US$56.7 million. As can be seen from Fig. 5, net exports of port services in Bulgaria in 2010-2016 had a negative value (Tab. 1.3), and in 2017-2022 they took a positive value and amounted to US$33 million.

Table 1.3 Indicators of port activities sector (port services, and also related infrastructure services and logistical services) in 2010-2016 (A) vs 2017-2022 (B)

Indicator, US$ million at current prices	Bulgaria		Georgia		Romania		Türkiye		Ukraine	
	A	B	A	B	A	B	A	B	A	B
Export	15.0	61.5	139.8	110.6	95.3	121.2	1085.9	2353.3	967.3	519.2
Import	32.9	28.7	2.7	0.7	34.0	75.7	33.9	322.7	114.9	150.0

In Georgia, the annual export of port services on average in 2010-2022 exceeds the import of services by 74.1 times. Net exports of services decreased in 2017-2022 and amounted to US$110 million (Fig. 1.5). It should be noted that Georgia's import of port services is decreasing annually (from US$5 million in current prices in 2010 to US$0.76 million in 2022). At the same time, exports of services increased from 2010 to 2015, when they reached their maximum of US$163.0 million. In the subsequent period up to 2021, a decline in port services exports was observed. In 2010, exports amounted to US$83.4 million in current prices, and in 2022 they amounted to US$119.2 million.

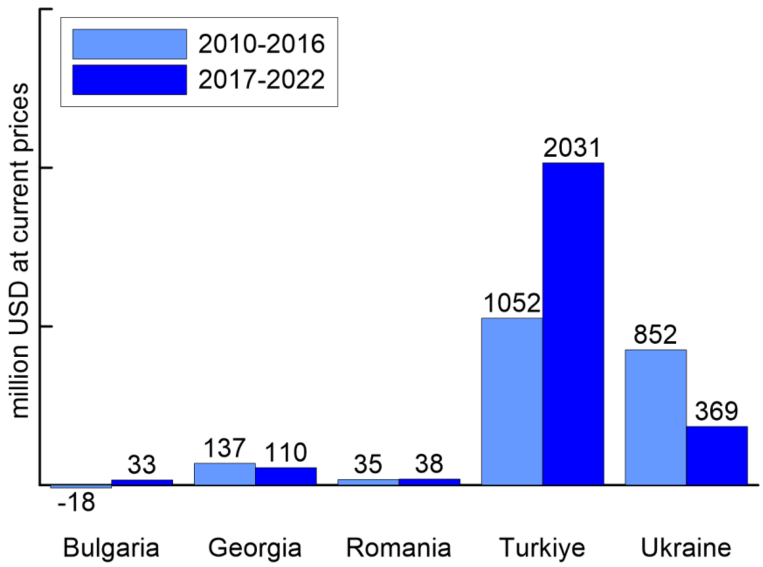

Fig. 1.5 Average net exports of port services, and also related infrastructure services and logistical services (US$ million at current prices) in 2010-2016 and in 2017-2022

In Romania, in 2013-2021, port services exports exceed imports by an average of 1.9 times. The lowest value of import of services was recorded in 2017 and amounted to US$25.9 million in current prices. The lowest export of port services was observed in 2018 and amounted to US$68.2 million. In 2019, the numbers increased, but in 2020, due to lockdowns, the volume of exports and imports decreased. In 2022, after the cancelation of restrictions, they amounted to: US$171.6 million – the export of services and US$109.9 million – the import of port services.

In Türkiye, port services exports exceeded imports during 2010-2022. Net exports increased by about 2 times (Fig. 1.5) from US$1.05 billion in 2010-2016 to US$2.03 billion in 2017-2022. Overall, service imports increased from less than US$35 million in current prices in 2010-2013 to US$590 million in 2018 and to US$602 million in 2022. The volume of port services exports saw two periods of rapid growth: in 2013, when it increased by 7.3 times and amounted to US$1.72 billion, and in 2021-2022, when it increased by another 1.7 times, reaching its maximum in 2022 of US$3.55 billion.

In Ukraine, as in other countries of the Black Sea basin, the export of port services exceeds import, however, there is a decrease in net exports (Fig. 1.5) from US$852 million in 2010-2016 to US$369 million in 2017-2022. Imports of services averaged US$131.1 million in 2010-2022, reaching US$218 million in 2013 and US$231 million in 2021. At the same time, the export of port services decreased from 2012 to 2018 by 2.45 times from US$1.2 billion to US$488 million in current prices. Between 2018 and 2021, there was an increase in the value of both imports and exports of port services.

For comparison, the Netherlands, where the largest European port of Rotterdam is located, in 2017-2022 the annual import of port and logistics services amounted to US$1.86 billion, the export of services amounted to US$3.48 billion. Net export amounted to US$1.61 billion.

1.4 Maritime transport

In Bulgaria, the average annual registered number of merchant vessels is 86 units. Over the past period, the fleet size has decreased by 28.4 %, reaching its lowest value of 78 vessels in 2023. As of 2023, the Bulgarian merchant fleet includes vessels with an average age of 43 years (Tab. 1.4).

In Georgia, the average merchant fleet size in 2011-2023 is 80 vessels, registered annually in the country. It should be noted that Georgia experienced the highest decrease in its merchant fleet, with its numbers decreasing by 87.9 % compared to 2011. In 2023, the fleet size was 26 vessels. At the same time, the fleet composition changed little until 2018. In 2011, the average age of ships was

32 years (built in 1979), in 2019 there was a decrease in the age of ships to 30 years and in subsequent years this figure has not changed, which indicates a constant renewal of the fleet with younger ships.

In Romania, the average annual merchant fleet size in 2011-2023 was 122 vessels. Overall, over the last decade, the number of vessels in the Romanian merchant fleet has decreased by 13.4 % compared to 2011, but within this period there was both a downward and upward trend. The most significant change in the size of the merchant fleet occurred in 2013, when it decreased by 29.2 % in one year, reaching its minimum number for the period under study – 104 vessels. In the following years, the number of Romanian merchant fleet vessels gradually increased to 127 vessels (in 2023). It should be added that the composition of the merchant fleet has changed little, which is reflected in the annual increase in the average age of ships (ships built in 1979).

In Türkiye, an average annually of 1252 vessels were registered, in 2011-2023. The Turkish merchant fleet is seeing a downward trend in its numbers. Over the past decade, it has decreased by 11.4 %, from 1,333 vessels in 2012 to 1,181 vessels in 2023. It should be noted that the Turkish merchant fleet is the youngest among the Black Sea countries. The average age of ships is 25 years and, in general, has remained virtually unchanged over the past ten years, i.e. there is a constant renewal of the merchant fleet.

Table 1.4 Indicators of maritime transport sector in 2010-2016 (A) vs 2017-2022 (B)

Indicator, unit	Bulgaria		Georgia		Romania		Türkiye		Ukraine	
	A	B	A	B	A	B	A	B	A	B
Number of vessels	91	81	126	40	124	120	1289	1220	455	409
Average age of vessels, years	34	39	34	32	34	39	25	26	32	39
Export of services, US$ million at current prices	42	57	6	21	169	130	1885	2367	39	33
Import of services, US$ million at current prices	632	730	253	333	208	280	4416	5893	542	729
Maritime transport of freight, million tons	27.2	28.6	8.4	12.2	41.7	50.7	143.0	176.8	3.4	2.0

In Ukraine, on average, 430 merchant vessels are registered annually. As of 2023, the number of merchant fleet units was 407, down 18.4 % from 2011. Overall, during the period under study, the lowest number of vessels was observed in 2018 (403 vessels), followed by a slight increase to 413 units in 2021. It should be noted that the composition of the Ukrainian merchant fleet remains practically unchanged. Thus, if the average age of ships in 2011 was 30 years (i.e. these are ships built in 1981), then in 2023 it was 41 years.

An analysis of freight shipping in the Black Sea showed that Bulgaria transports an average of 27.9 million tons of cargo annually in 2011-2022. The highest values were recorded in 2017 and 2019 (31.0 million tons), a decrease in the volume of freight shipping was observed in 2011 and 2020 (25.2 and 25.3 million tons, respectively).

In Georgia, on average, 10.3 million tons of cargo is transported by sea every year. In recent years, this indicator has increased by 1.8 times compared to the previous period. The largest volume of freight shipping was recorded in 2021 and amounted to 16.5 million tons.

In Romania, on average, maritime transport carries 46.2 million tons of cargo annually. At the same time, an increase in the volume of freight shipping is noted every year. Thus, the average annual volume of cargo transported by sea in 2017-2022 exceeds the same indicator for the period 2011-2016 by 1.2 times.

In Türkiye, an average of 159.9 million tons of cargo is transported annually by sea in the Black Sea area. Moreover, in 2017-2022, the volume of freight shipping exceeded the same indicator for the period 2011-2016 by 1.23 times.

In Ukraine, in 2011-2021, on average 2.7 million tons of cargo are transported annually by sea transport. At the same time, in 2017-2021, there was a decrease in the volume of freight shipping by 1.75 times compared to 2011-2016.

The import of maritime freight transport and related services exceeds export. In Bulgaria, imports of services exceed exports by 13.7 times. In 2010-2022, the average annual import of services amounted to US$677 million in current prices, and the value of export of services was US$49.28 million. High values of service imports were recorded in 2014 (US$983.22 million), 2017 (US$1.07 billion) and 2022 (US$989.246 million). It should be noted that the amount of exports of maritime freight transport in Bulgaria has increased in recent years from US$33.23 million in 2010 to US$73.00 million in 2022. Net exports are negative (Fig. 1.6, Table D.1-D.2), which indicates that in Bulgaria, imports of services exceed exports. In recent years, there has been a decrease in net exports from US$-589 million in 2010-2016 to US$-673 million in 2017-2022.

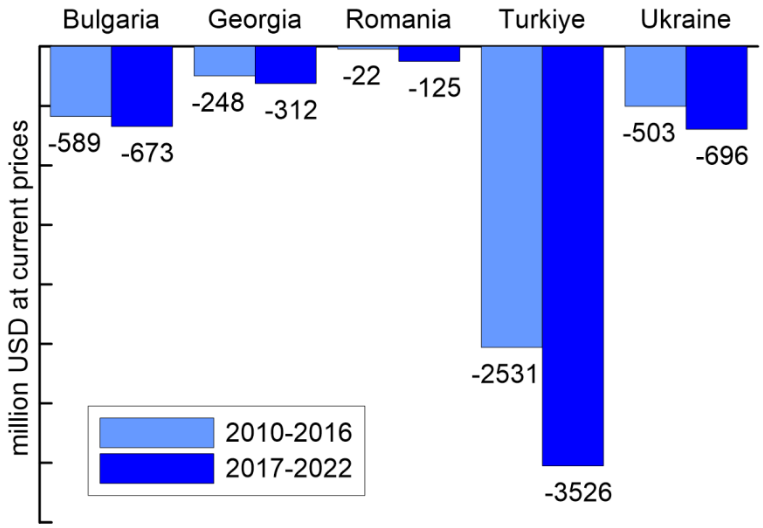

Fig. 1.6 Average net exports of maritime freight transport and related services (US$ million at current prices) in 2010-2016 and in 2017-2022

In Georgia, the average annual import of maritime freight transport and related services exceeds the average annual export by 22.7 times. Net exports of services in 2010-2016 amounted to US$-248 million (Fig. 1.6), and in 2017-2022 it decreased to US$-312 million. At the same time, since 2010, there has been an increase in the annual amount of import and export of services. Thus, import of services increased from US$149.28 million in current prices in 2010 to US$484.02 million in 2022, and export of services increased from US$8.3 million in current prices in 2010 to US$78.53 million in 2022.

Data on maritime freight transport and related services in Romania in the UNCTAD database covers the period 2013-2021. In Romania, the average annual import of services exceeds exports by 1.7 times and amounts to US$247.88 million and US$147.23 million, respectively. It should be noted that in 2021, imports of services were 2.3 times higher than in previous years and amounted to US$493.4 million. The highest rate of services exports was recorded in 2014 (US$236.84 million), after which a decline was observed. Net exports of services decreased and reached US$-125 million in 2017-2022.

In Türkiye, the average annual import of maritime freight transport and related services is 2.4 times higher than the export, amounting to US$5.1 billion and US$2.11 billion, respectively. From 2010 to 2022, imports of services doubled and amounted to US$10.08 billion (in 2022). Moreover, its lowest value was observed in 2015-2017 (US$3.4 billion - US$3.5 billion in current prices). Exports of services in 2022 increased by 2 times compared to 2010, and amounted to US$2.5 billion. At the same time, the maximum export of cargo transportation services by sea was observed in 2017 and amounted to US$2.7 billion in current prices. In Türkiye, the value of net exports decreased from US$-2.5 billion at current prices in 2010-2016 to US$-3.5 billion in 2017-2022.

In Ukraine, the average annual amount of imports of maritime freight transport and related services exceeds the amount of exports by 17.5 times and their values are US$628.15 million and US$35.85 million, respectively. At the same time, opposite trends are observed. Thus, in 2022, imports of services increased by 1.2 times compared to 2010 and amounted to US$1.03 billion. This resulted in the net export value decreasing in 2017-2022 to US$-696 million. The lowest values of import of services were in 2015-2016, when foreign companies provided Ukraine with sea freight services for the amount US$340 million – US$348 million in current prices. The highest rates of services export were recorded in 2011 and 2013, when Ukrainian companies provided services to foreign companies for the amount US$50 million and US$54 million in current prices, respectively. The lowest values of services exports were recorded in 2015 and 2022 and amounted to US$14 million and US$10 million, respectively.

For comparison, Greece (the largest owner of merchant fleet in Europe) imports in 2017-2022 of services of maritime freight transport and related services annually on US$187.0 million, and exports services worth US$12.78 billion. Net exports of services is US$12.59 billion.

1.5 Shipbuilding

Analysis of UNCTAD data for the period 2014-2023 cover seagoing propelled merchant ships of 100 gross tons and above, excluding inland waterway vessels, fishing vessels, military vessels, yachts, and offshore fixed and mobile platforms and barges (with the exception of floating production, storage and offloading vessels [FSPO] and drillshipsdrill ships), which were produced at national shipyards of the Black Sea countries. Bulgaria's highest production was in 2015, when it produced 2797 gross tonnage of vessels, representing 0.004 % of the world's total gross tonnage produced that year. In 2015-2019, shipyards produced an average of 0.0028% of the world's gross tonnage of seagoing merchant ships per year. In 2014 and 2020-2023, no seagoing ships were recorded.

As for Georgia, according to the UNCTAD database, there is no shipbuilding activity there. In Romania, the total average annual gross tonnage of seagoing merchant ships produced in shipyards is 243.72 thousand tons, which corresponds to a share of 0.37% of the world's total gross tonnage of ships produced. The highest rates of ship production in Romania were recorded in 2016, when seagoing vessels with a total gross tonnage of 848.26 thousand tons were produced, which represented 1.27 % of the world total production that year. The Romanian shipbuilding industry has a long tradition and, although hit by the economic crisis, is now increasing its competitiveness through investments in green technologies and innovation capacity [50]. Türkiye on average annually in 2014-2023 produced at its shipyards marine merchant vessels with a total gross tonnage of 111.15 thousand tons, which is an average of 0.18 % of world production. The highest rates were observed in 2014, 2019, 2021 (140.24 thousand tons, 146.93 thousand tons and 132.47 thousand tons, respectively), which accounted for a share of the global gross tonnage of maritime merchant ships produced in these years – 0.22 %. In Türkiye, the shipbuilding and ship repair sector is concentrated in the Mediterranean basin and specializes in chemical tankers, mega-yachts and offshore infrastructure. Shipbuilding in Ukraine produces seagoing merchant vessels not every year. On average, in 2014-2023, the annual indicator of the total gross tonnage of ships produced by Ukrainian shipyards is 956 tons, which corresponds to 0.001 % of the world's total production.

On average, in 2014-2023, the EU countries annually produced marine merchant vessels with a total gross tonnage of 17.83 million tons, which is 2.9 % of world production. According to data for 2024, the largest producers of seagoing merchant vessels are East Asian countries: China – 54.6 % of world production, South Korea – 28.0 % and Japan 12.6 %.

CHAPTER 2: DEVELOPMENT TRENDS OF UKRAINE'S BLUE ECONOMY

At the present stage of Ukraine's development, the factor of establishing itself as a maritime state is of particular importance, based on its spatial and geophysical features, place and role in the global and regional system of international relations. Ukraine received the status of a maritime state, having made a significant contribution to the development of navigation and the study of the World Ocean, as well as due to its favorable geographical position, in particular, the length of the sea coast and the area of the water space. Ukraine has the largest length of the sea coast among the states of the Azov-Black Sea basin (2759.2 kilometers) and more than 72 thousand square kilometers of exclusive maritime economic zone.

A significant part of the national gross domestic product is formed by five regions of Ukraine that have access to the sea and occupy about 27 percent of the territory. Most of the population on their territory lives at a distance of no more than 60 kilometers from the sea and is closely associated with maritime activities.

As a result of the temporary occupation by the Russian Federation, Ukraine is deprived of the opportunity to use a significant part of its naval potential, national property, including the infrastructure of maritime transport and energy on the shelf of the Black and Azov Seas, the system of maritime education and science, established economic ties between enterprises, and to carry out maritime activities. The approximate cost of losses, excluding private business, is an amount equal to the annual gross domestic product of Ukraine. Figure 2.1 shows Exclusive Economic Zone (EEZ), and other waters under Ukrainian jurisdiction, which covers about 144,000 km^2.

Fig. 2.1 The Ukrainian EEZ and shelf waters in the Black and Azov Seas [51]

The Black Sea region of Ukraine has a large coastline and an advantageous geographical location, being at the intersection of international transport routes, which creates favorable conditions for the development of the maritime transport sector. Marine and coastal ecosystems of the northwestern part of the Black Sea provide a number of ecosystem services, namely, providing the local population with food, various recreational services, which include treatment with the marine climate and mud of the estuaries [52]. All these conditions make the development of the blue economy one of the most promising areas of development of the sectors of the Ukrainian economy.

2.1 Economic indicators

2.1.1 Population and GDP

According to the State Statistics Service of Ukraine [24], as of February 1, 2022, the resident population in Ukraine was 40.961 million persons. In July 2024, the country's population was estimated at 35.8 million people. By 2051, according to the forecast of the Institute of Demography and Quality of Life Problems of the National Academy of Sciences, the population of Ukraine will be 25.2 million people. At the same time, at the beginning of 2022, 4.427 million people lived in the coastal regions of the Black Sea (Odesa, Mykolaiv, Kherson regions).

According to the World Bank [53], Ukraine's GDP in 2023 amounted to USD 178.757 billion in current prices, which is US$29.07 billion more than the average for the period 2010-2023. As can be seen from Fig. 2.2, the years with the best indicators were 2013 and 2021, when GDP amounted to US$190.5 and US$199.7 billion, respectively. The lowest GDP indicators were observed in 2015-2016, when its values decreased to US$91.0 and US$93.4 billion, respectively.

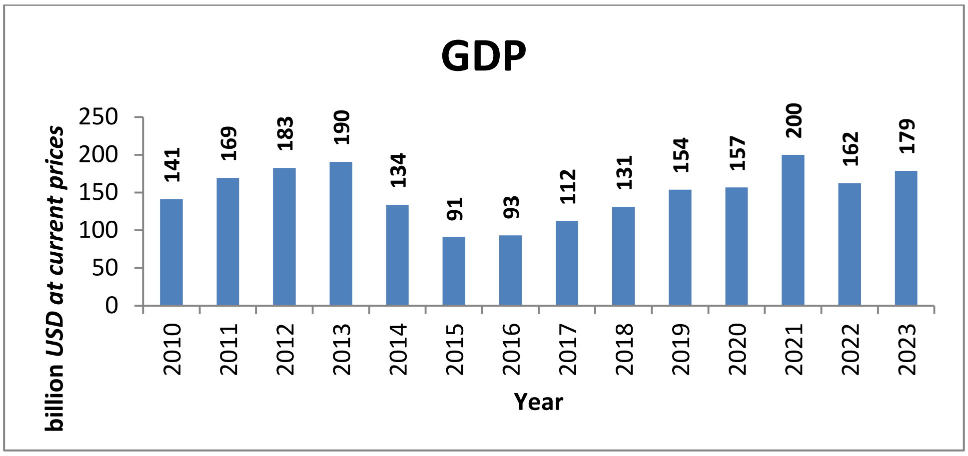

Fig. 2.2 Ukraine's GDP (US$ billion at current prices)

The indicator of economic activity of the region is Gross Regional Product (GRP), which is measures the final market value of all goods and services produced in the region of study. According to the State Statistics Service, the GRP of Odesa, Mykolaiv and Kherson regions in 2021 amounted to 8.9 % of Ukraine's GDP, which is 0.2 % lower than in 2016 and 2020 and 0.3% higher than in 2018 (Table 2.1).

Table 2.1 Share of gross regional product in general total (%)

Regions	2015	2016	2017	2018	2019	2020	2021
Mykolayiv	2.4	2.5	2.3	2.2	2.3	2.3	2.3
Odesa	5.0	5.0	5.0	4.9	5.0	5.2	5.0
Kherson	1.6	1.6	1.6	1.5	1.6	1.6	1.6

Of these three regions, Odesa region has the highest GRP (5.0 % in 2021). Mykolaiv and Kherson regions accounted for 2.3 % and 1.6 % of GRP in 2021, respectively.

2.1.2 Capture fisheries and aquaculture

The Ukrainian coastal fisheries consist of two main commercial sectors: artisanal (small-scale) and industrial (large-scale). The artisanal sector is characterized by small boats averaging 4-5 m in length using passive fishing gear such as set traps (‘stavniki’) and fixed nets.

The industrial sector operates mainly trawler-seiner vessels averaging 18-24 m in length (V. Shlyakhov, pers. obs.) [51], as well as multi-purpose type vessels using other net-types and longlines. In 2000, there were 95 operational industrial fishing vessels in the Black and Azov Seas, which decreased to about 80 by 2004. These vessels target mainly anchovy, sprat, goby, and so-iuy mullet. The sprat bottom-trawl fishery began in the mid-1970s and was at first very intensive, with over 120,000 bottom-trawl hauls conducted in the north-west portion of the Black Sea from 1979 until 1986.

According to FAO data [20], the main species of marine living resources harvested by Ukraine in the Black Sea in 2010-2022 are several European (*Sprattus sprattus*) (average annual production – 7.12 thousand tons), European anchovy (*Engraulis encrasicolus*) (6.35 thousand tons), rapana (*Rapana venosa*) (2.49 thousand tons), sand eels (*Atherina boyeri*) (640 tons), bull (*Gobiidae*) (360 tons).

In general, Ukraine's share in 2018-2022 accounts for 2.2% of the total volume of marine living resources harvested in the Black Sea. On average, in 2010-2022, Ukraine annually harvested 18.2 thousand tons of live weight. A significant decrease in catches was noted in 2014 after the annexation of Crimea, when production decreased by 9.7 times. Thus, in 2013, the largest fishing centers in Ukraine were located in Sevastopol, Kerch, Odessa, Berdyansk, and in 2014 the situation changed dramatically [46]. As a result of the annexation of Crimea, Ukraine lost a significant part of its fisheries. By 2014, more than 60% of the total production of aquatic biological resources in Ukraine was produced in Crimea. The average annual catch in 2010-2016 was 27.1 thousand tons of marine living resources, and in 2017-2022 this figure decreased to 7.8 thousand tons. A significant decrease in catches occurred in 2022 after the closure of navigation in the northwestern part of the Black Sea due to military operations, as a result of which Ukraine caught 164 tons of marine living resources this year (Fig. 2.3). In addition to the above, the reduction in fishing in the open sea is influenced by the outdated resource of the fishing fleet, outdated ship repair and port infrastructure, technologies for searching and harvesting fish on domestic vessels, and a low level of state investment in the fixed capital of domestic fisheries enterprises [47].

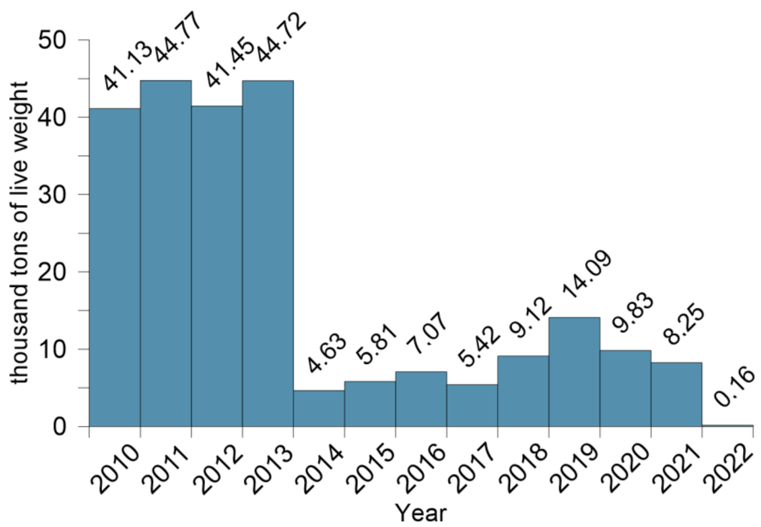

Fig. 2.3 Capture production in thousands tons of live weight

Ukraine ranks third among the Black Sea basin countries in terms of the volume of aquaculture processing (an average of 89.12 thousand tons of live weight annually). It should be noted that during the period from 2010 to 2021 in Ukraine, the amount of processing has decreased by 3.5 times.

Mariculture is today one of the most promising innovative industries of the blue economy in the Black Sea region. According to FAO, in Ukraine in 2010-2015, an average of 78.1 tons of mariculture live weight were grown annually, worth US$93.7 thousand (Fig. 2.4). This indicator was formed due to the cultivation of Mediterranean mussels (*Mytilus galloprovincialis*). It should be added that in Ukraine, aquaculture was also grown in brackish water (Black Sea estuaries) with an average annual volume of 647.3 tons, worth US$1.7 million. The main species grown in brackish water was mullet (*Mugil soiuy)*, the average annual production of which was 634 tons, worth US$1.65 million.

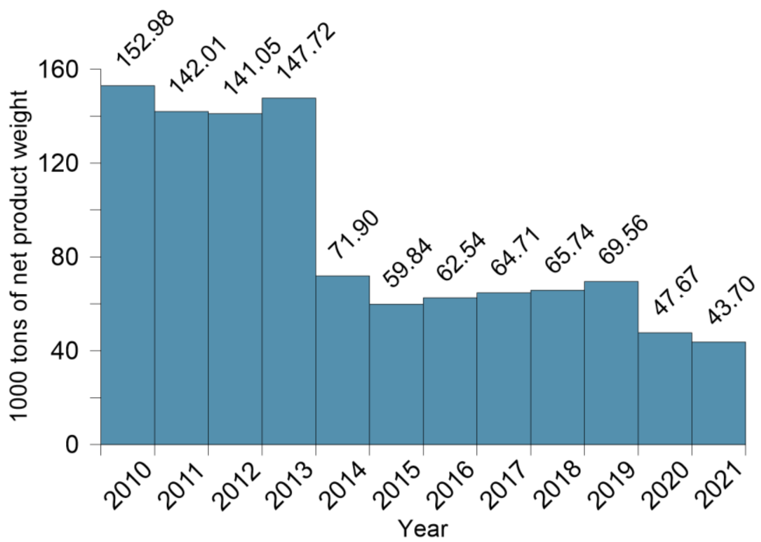

Fig. 2.4 Aquatic processed production in thousands tons of net product weight

According to the World Bank [54] Ukrainian aquaculture production in Black Sea amounted to 21424.6 metric tons in 2015, 18603.71 metric tons in 2019, 16881.8 metric tons in 2021 and 14630 metric tons in 2022.

2.1.3 Marine non-living resources

Significant reserves of minerals have been explored on the Ukrainian shelf of the Black and Azov Seas, including up to 1,583.5 billion cubic meters of natural gas and up to 409.8 million tons of crude oil, which is more than 30 percent of Ukraine's total hydrocarbon reserves. However, only 4 percent of them have been extracted, while up to 70 percent of explored hydrocarbon reserves come from coastal deposits.

There are gas fields on the shelf in the northwestern part of the Black Sea. Golitsynskoye gas condensate field is the first hydrocarbon field discovered in the Black Sea. It is located 70 km from the coast at a sea depth of over 50 m. It was discovered in 1974. It was put into operation in 1983. Production was carried out from a cluster of fixed platforms. Odesskoye and Bezymyannoye natural gas fields. The total reserves are over 22 billion cubic meters. The fields are located 155 km from the Crimean coast at a sea depth of 30-60 m. Shtormovoe gas condensate field is the largest offshore field in Ukraine. It was put into operation in 1993. It is located 70 km from the coast at a sea depth of 53 meters. Production was carried out from several fixed platforms. The Arkhangelsk gas field is located 60 km from the coast at a water depth of about 50 meters. It was commissioned in 1992. Production was carried out from several fixed platforms. In 2010, the BK-1 fixed platform was installed, an underwater gas pipeline was built and ten wells were drilled.

In the north-eastern part of the Black Sea is the Subbotina field – the first offshore oil field discovered in Ukraine in 2005. It is located 23 km from the Kerch Peninsula at a sea depth of 30 meters. Industrial reserves are 6 million tons.

In March 2014, during the Russian intervention in Crimea, units of the Russian Armed Forces seized Ukrainian drilling rigs belonging to the company Chornomornaftogaz. In December 2015, the drilling rigs were relocated to Russian-controlled Crimean waters. Since the start of the war in 2022, the rigs have not been in operation and gas production at the fields has not been carried out.

2.1.4 Maritime transport and port infrastructure

Today, Ukraine has 10 continental sea ports – Reni, Izmail, Ust-Dunaisk, Belgorod-Dnestrovsky, Chornomorsk, Odessa, Pivdennyi, Mykolaiv, Olvia, Kherson. At the same time, 8 sea ports are located on the occupied territory – Skadovsk, Berdyansk, Mariupol, Evpatoria, Sevastopol, Yalta, Feodosia, Kerch. In 2017-2021, Ukrainian ports processed an average of 148.2 million tons of cargo annually. Thus, according to data for 2021, the largest Black Sea ports processed (million tons) of cargo: Pivdennyi – 53.5, Mykolaiv – 29.9, Chornomorsk – 25.6, Odesa – 22.6 (Fig. 2.5).

The main part of cargo passing through Ukrainian seaports consists of goods destined for export (about 76% of the total cargo volume). Imports of goods account for about 16% of the total cargo volume. About 7% are transit cargo. And a little more than 1% is cargo that is shipped on coastal shipping (Fig. 2.6, Table F.1).

In Ukraine, as in other countries of the Black Sea basin, the amount of exports of port and related infrastructure and logistics services exceeds the amount of imports. Imports of services on average in 2010-2022 amounted to US$131.1 million in current prices and reached US$218 million in current prices in 2013 and US$231 million in 2021 (Fig. 2.7).

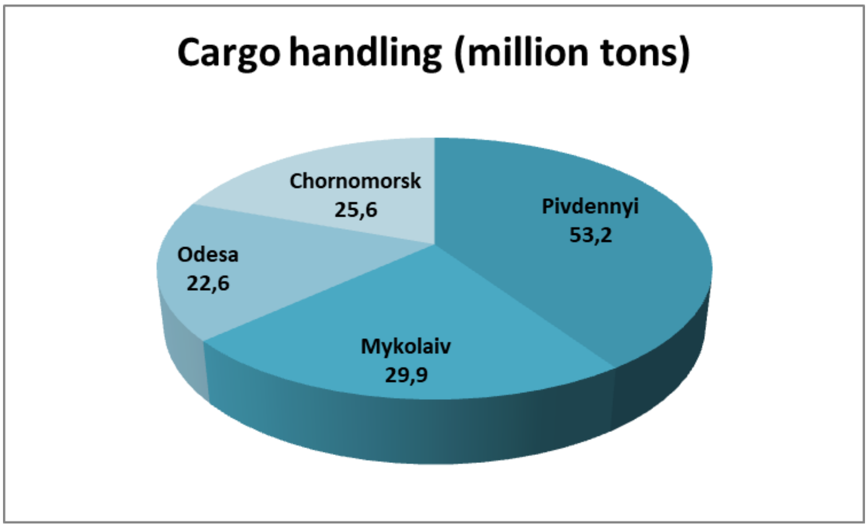

Fig. 2.5 Cargo handling (million tons) in 2017-2021 in the seaports of Ukraine

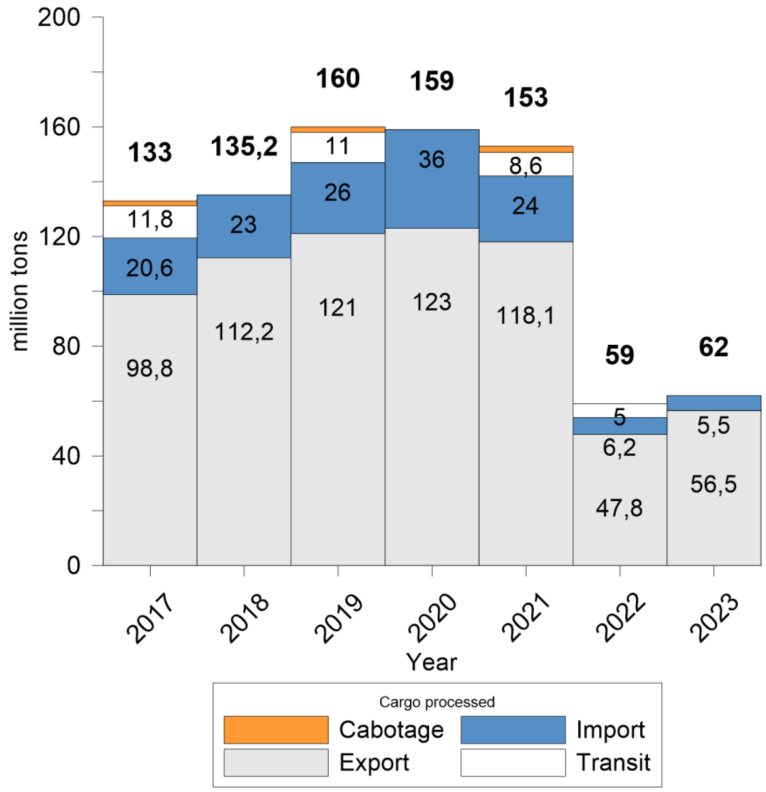

Fig. 2.6 Cargo processed in the ports of Ukraine (million tons).
Numbers in bold – total cargo processed. In 2018, 2020, 2022, 2023, there is no data on the handling of cabotage cargo

Exports of port services on average amounted to US$760 million and decreased from 2012 to 2018 by 2.45 times from US$1198 million to US$488 million in current prices. In the period from 2018 to 2021, there was an increase in both imports and exports of port services. Net exports of port and related logistics services in 2010-2016 amounted to US$852 million in current prices, and in 2017-2022 it was noted to decrease to US$369 million.

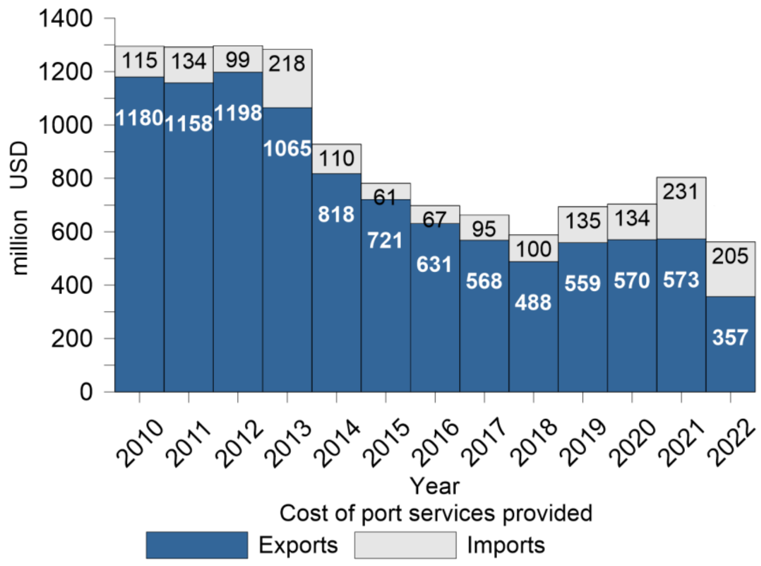

Fig. 2.7 Cost of port services (related infrastructure services and logistical services) provided (in million USD at current prices)

Data analysis for the period 2014-2023 on the production of seagoing merchant vessels of 100 gross tonnage and over, excluding inland navigation vessels, fishing vessels, military vessels, yachts and offshore stationary and mobile platforms, as well as barges (excluding floating production, storage and offloading [FSPO] vessels and drillships) at the national shipyards of Ukraine showed that their production does not occur every year. On average in 2014-2023, the annual indicator of the total gross tonnage of vessels produced by Ukrainian shipyards is 956 tons, which corresponds to 0.001% of global production (Fig. 2.8).

The average annual number of Ukrainian merchant fleet in 2010-2023 was 430 vessels. According to data for 2023, the number of the fleet decreased by 18.4% compared to 2011 and amounted to 407 vessels (Fig. 2.9). In general, over the studied period, the smallest registered number of vessels was noted in 2018 (403 vessels), then an increase to 413 units was observed in 2021. It should be noted that the composition of the Ukrainian merchant fleet practically does not change. Thus, if the average age of vessels in 2011 was 30 years (i.e. these are vessels built in 1981), then in 2023 it was 41 years.

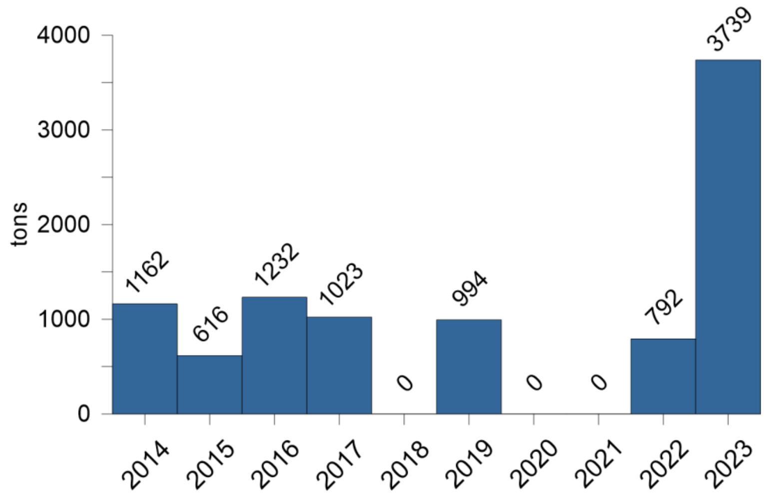

Fig. 2.8 Gross tonnage of ships produced (tons)

An analysis of freight shipping in the Black Sea showed that in 2011-2021, Ukraine transported an average of 2.7 million tons of cargo by sea annually. In addition, in 2017-2021 a 1.75 times decrease in the volume of cargo was noted compared to 2011-2016.

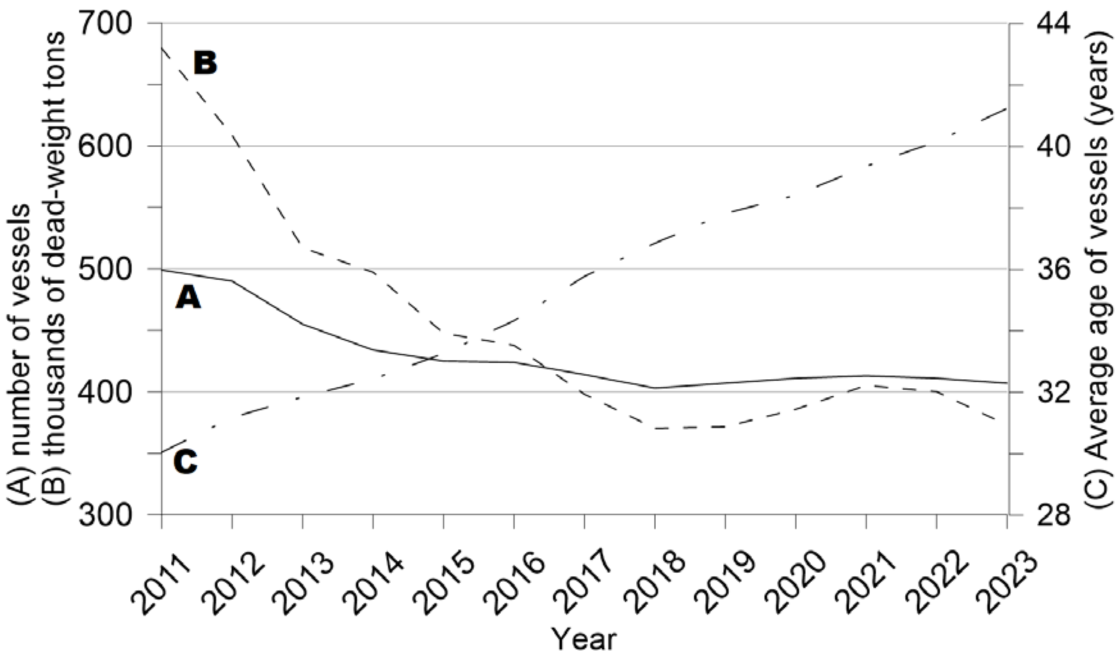

Fig. 2.9 Merchant fleet registered in Ukraine:
(A) – number of vessels; (B) – dead-weight, (C) – average age of vessels

In the field of maritime freight transportation services in Ukraine, imports of services exceed exports of services. The average annual amount of imports of services exceeds the amount of exports by 17.5 times and their values are US$628.15 million and US$35.85 million in current prices, respectively. At the same time, opposite trends are observed. Thus, in 2022, imports of services increased by 1.2 times compared to 2010 and amounted to US$1.02 billion. The lowest value of imports of services was in 2015-2016, when foreign companies provided Ukraine with maritime freight transportation services worth US$340-348 million in current prices. The highest indicators of exports of services were noted in 2011 and 2013, when Ukrainian companies provided services to foreign companies worth US$50 million and US$54 million in current prices, respectively. The lowest indicators of services exports were noted in 2015 and 2022 and amounted to US$14 million and US$10 million, respectively (Fig. 2.10).

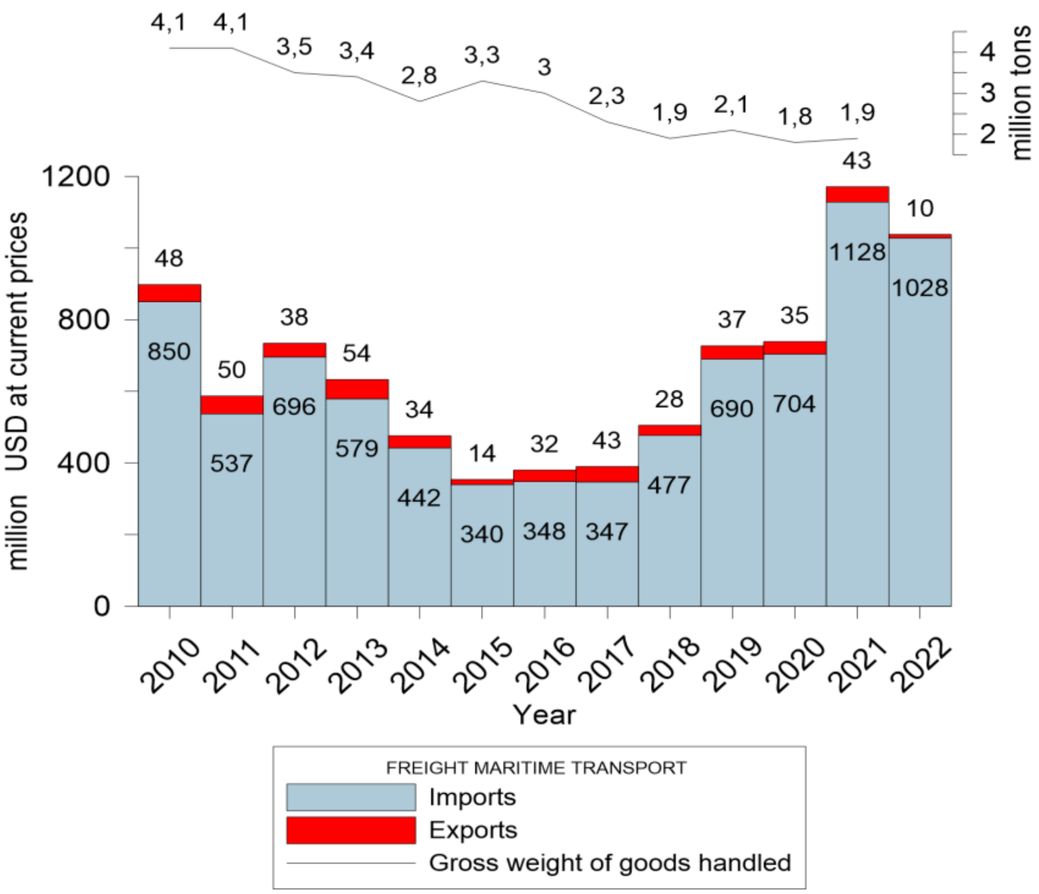

Fig. 2.10 Cost of freight maritime transport service provided (in million USD at current prices) and gross weight of goods handled by maritime transport (in million tons)

Net exports of maritime freight services in 2010-2016 amounted to US$-503.1 million in current prices. In 2017-2022, net exports decreased to US$-696 million.

2.1.5 Coastal tourism

Tourism sector in Ukraine according to World Travel & Tourism Council [55] made in 2023 a total contribution to GDP of US$7.4 billion what was it 4 % from Ukraine's GDP. In total, 360 thousand people were employed in the tourism sector in 2023, which accounted for 3.2 % of total employment in Ukraine.

The presence of attractive and diverse landscapes, sources of mineral waters and mud creates all the conditions for the formation of a highly developed industrial recreational and tourist complex. However, the medical and health-improving base, as well as especially valuable and unique natural therapeutic resources, are not used effectively enough. The material and technical base of recreational and tourist institutions, the range and quality of services do not meet world standards, which reduces the competitiveness of the region in the international market of these services.

In 2018 number of places in collective means of accommodation in Odesa, Mykolaiv and Kherson regions amounted to 55628 and in the following 2 years it decreased by 10000 numbers. At the same time number of rooms in hotels and similar means of accommodation increased from 5045 in 2018 to 5127 in 2020. It should be noted that the restrictions imposed during the COVID-19 period had a negative impact on tourism activity in the Black Sea region of Ukraine. So, number of overnight stays in collective means of accommodation was 2,556,360 in 2018 and decreased to 1,228,648 in 2020, also the number of persons who were in collective means of accommodation decreased by approximately 2 times in 2020 compared to 2018 and amounted to 278,022 and 537,433, respectively. Thus, it can be seen that in 2020 there was a significant decrease in the indicators of the tourism sector, the reason for which is the restrictions caused by the COVID-19 pandemic.

2.2 Environment Data

2.2.1 Sustainability measures

Today, Ukraine attaches great importance to ensuring security and stabilizing the situation in the Black Sea region, guided by its national interests, the foundations and principles of its foreign policy [39, 40]. For the development of

Ukraine, one of the main directions is the blue economy development. In 2009, the “Maritime Doctrine of Ukraine for the period up to 2035” [56] was developed, containing the strategy and main directions for the further development of Ukraine as a maritime state.

In 2017, the Cabinet of Ministers of Ukraine issued Resolution "On approval of the Strategy for the implementation of the provisions of EU directives and regulations in the field of international maritime and inland waterway transport ("road map")" [57] within the framework of which the state standards of Ukraine must be brought into line with EU standards.

In 2021, the Cabinet of Ministers of Ukraine issued the Resolution "On approval of an action plan to support the cultural sector, protect cultural heritage, develop creative industries and tourism" (№ 84-p from 03.02.2021) [58], which is aimed at developing the tourism industry and preserving natural locations for ecotourism.

In accordance with Ukraine's commitments to implement the "Association Agreement between the European Union and Ukraine", in 2023, the Cabinet of Ministers of Ukraine issued the Resolution “On approval of the Strategy for the development of the fisheries industry of Ukraine for the period up to 2030 and approval of the operational plan of measures for its implementation in 2023-2025” [59]. The Strategy sets out a roadmap for reforming the fisheries industry in the medium term. The reform process entailed significant updates to the legislative framework of the industry, which contributed to the activation of the aquaculture sector in Ukraine.

To develop a comprehensive strategy for the development of the maritime industry, in particular merchant shipping, taking into account the results of the economic and legal analysis of global trends in the relevant field, the National Transport Strategy of Ukraine for the period until 2030 [60], and the Strategy for the Development of Seaports of Ukraine for the period until 2038 [61] were developed.

All current issues regarding the improvement of the legislative framework for the development of the Blue Economy of Ukraine, as well as the improvement of the maritime transport sector through the full implementation of international conventions in the field of navigation and accession to new international treaties in the relevant field are reflected in the Merchant Shipping Code of Ukraine [62], the Water Code of Ukraine [63], the Land Code of Ukraine [64], the Laws of Ukraine “On Transport” [65], “On Seaports of Ukraine” [66], “On Fisheries, Industrial Fishing and Protection of Aquatic Bioresources” [67], “On the Basic Principles of State Supervision (Control) in the Sphere of Economic Activity” [68] and other acts of legislation in accordance with the international legal regime of navigation;

comprehensive legislative regulation of the functioning of inland water and sea transport.

Ukraine's signing of the Convention for the Protection of the Black Sea against Pollution [69], and the Protocol on Cooperation in Combating Pollution of the Marine Environment of the Black Sea by Oil and Other Harmful Substances in Emergency Situations contributed to the improvement of the response system to marine water pollution, including through the development of a national action plan for responding to emergency situations related to marine pollution by oil and other hazardous and harmful substances.

2.2.2 Conservation status

Significant areas of coastal and marine waters are protected in 20 objects of the national nature reserve fund, including water and biological lands of international importance. These include objects located in the northwestern Black Sea region, such as: Danube Biosphere Reserve, Tuzlovskie Limany National Nature Park, Nizhnednestrovskiy National Nature Park, Beloberezh'ye Svyatoslava National Nature Park, Dzharylgach National Nature Park and others (Fig. 2.11).

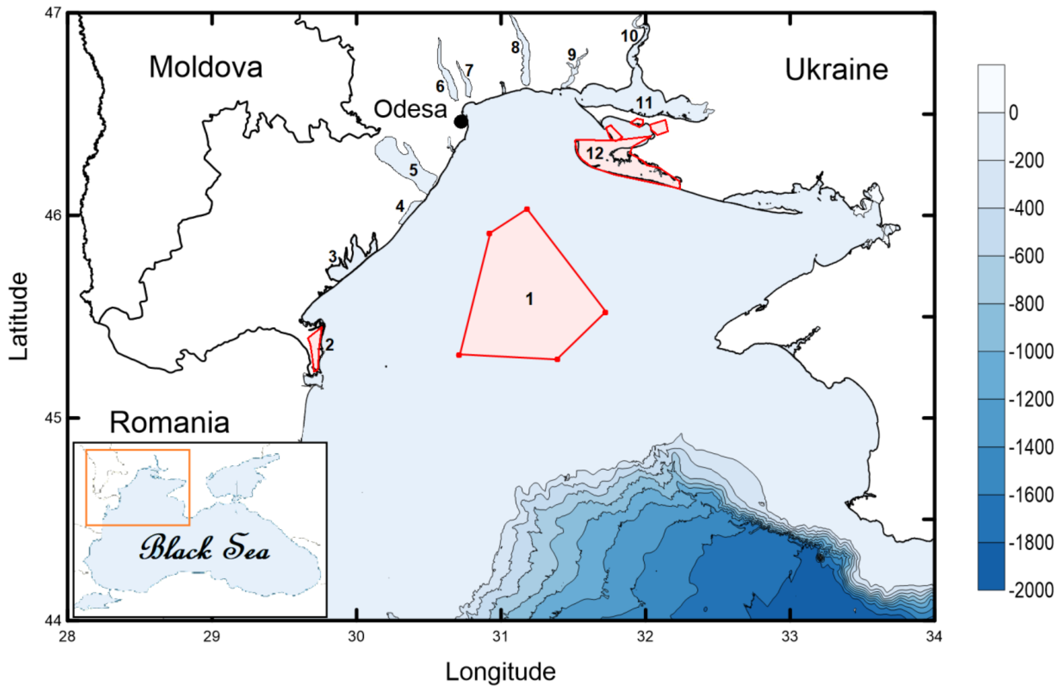

Fig. 2.11 Map of the northwestern part of the Black Sea: 1 – the boundaries of botanical reserve national significance “Zernov's *Phyllophora* Field”, 2 – Danube Biosphere Reserve, 3 – Tuzly Limans, 4 – Budak Liman, 5 – Dniester Liman, 6 – Khadzhibey Liman, 7 – Kuialnyk Liman, 8 – Tiligulskiy Liman, 9 – Berezanskyi Liman, 10 – Bug Liman, 11 – Dnieper Liman, 12 – Black Sea Biosphere Reserve

The wetlands of the North-Western Black Sea region are an important component of ecological corridors and an indispensable link in the ecological network. They are part of the Emerald Network, which is an area of special conservation interest and intended for long-term survival that, in accordance with the Berne Convention, is subject to conservation (Fig. 2.12).

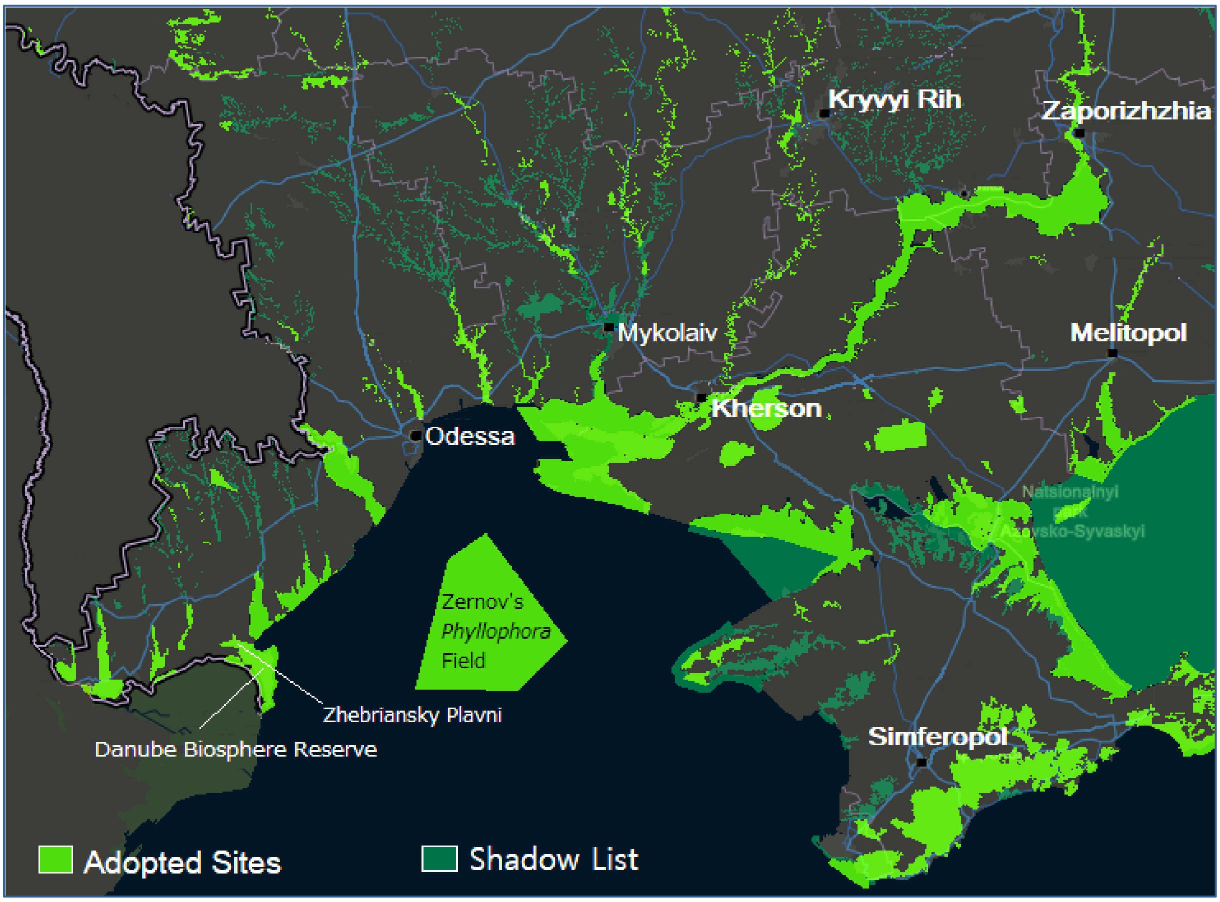

Fig. 2.12 North-Western Black Sea region.
The network of European significance protected areas ‘Emerald Network of Ukraine’ (highlighted in green) [70]

The processes of pollution and degradation of the wetlands of the North-Western Black Sea region are associated with industrial, agricultural and recreational tourism activities, as well as with the influence of the local population, eutrophication of water bodies, etc.

Industry is one of the main sources of pollution, both air and water bodies. In the Odessa region alone, there are 615 enterprises that have a significant harmful impact on the state of the air and human health. Of these, 20 enterprises, predominantly in the oil, energy and cement industries, have the greatest impact.

The ecological state of the Azov and Black Seas remains extremely unsatisfactory. The volume of pollutants discharged into the territory of Ukraine alone reaches about 350 thousand tons annually. The level of seawater pollution in certain coastal areas exceeds the maximum permissible concentrations of petroleum products, phosphorus and phenols by an average of five times, which causes the death of animals and plants.

2.2.3 Ecosystem services

The concept of "ecosystem services" is absent in Ukrainian legislation, therefore, their inclusion in decision-making is not very common, but the Law of Ukraine "Basic principles (strategy) of the state environmental policy of Ukraine for the period up to 2030" notes the feasibility of "introducing the ecosystem approach into sectoral policy and improving the system of integrated environmental management".

Marine and coastal ecosystems play a critical role in providing key services such as food supply, sequestration of anthropogenic carbon, waste management, biological regulation and the provision of habitat for hydrobionts. However, along with other ecosystems, today they are under serious anthropogenic pressure.

For example, the northwestern part of the Black Sea is an important fishing area that provides the local population with food and a profitable economic item, but eutrophication processes often lead to the development of hypoxia and even anoxia, which, in turn, led to the death of fish, mussels and other water filter feeders. Only in 1973-1990, within the northwestern part of the Black Sea, losses amounted to 60 million tons (including 5 million tons of fish). In the 1990s, the ecological situation improved slightly, and fish and bivalve kills occurred less frequently and in smaller areas [71].

The northwestern part of the sea basin is characterized by the unique resources of the Zernov's *Phyllophora* Field − the concentration of algae macrophyte, the dominant species among which are red algae of the *Phyllophoraceae* family. As a result of more than half a century of intensive industrial mining of the layer-forming form of the species *Phyllophora crispa* for the industrial production of agar-agar, as well as due to the anthropogenic impact on the marine environment of the NW Black Sea, a decrease in the genetic diversity of hydrobionts of the phyllophora field was recorded.

In addition, a decrease in water transparency led to a decrease in the activity of photosynthesis processes and the death of a large number of benthic algae at depths of 20-60 m; the area of the phyllophora field decreased from 11000 km^2 in the 1950s to 500 km^2 in the 1980s, and the biomass decreased from 10 million tons to 0.2 million tons, respectively. Natural and anthropogenic changes have led to the degradation of specific species of invertebrates and fish with a red coloration, that is, part of the "phyllophora biocenosis".

In recent years, there is a slight trend to the phyllophora field restoration, which is a botanical reserve of national importance. Atmospheric influence is manifested in the fact that biogenic elements and pollutants are brought into the sea basin with air masses, which contributes to the development of eutrophication processes, and also negatively affects the state and quality of sea water and bottom sediments.

At the same time, atmospheric processes contribute to climate regulation in the region by mitigating the occurrence of drought events on the coast and thus providing regulating ecosystem services. The impact of the warm sea basin extends inland at 140-280 km, thus, the sea is regulates the climatic conditions of the southern coast of Ukraine, covering the entire coastal zone of the North-Western Black Sea region. Breeze circulation of air masses plays a role in the formation of mesoclimatic conditions, and also contributes to the transport of pollutants, thus affecting on air quality in the coastal strip.

Wetlands, widespread in the coastal zone of the North-Western Black Sea region, regulate such processes as: accumulation and storage of fresh water, water filtration, absorption from the atmosphere and accumulation of carbon, return of oxygen to the atmosphere, regulation of surface runoff, stabilization of groundwater levels, participation in the formation of climatic conditions (precipitation, humidity and air temperature), prevention and containment of erosion processes, maintenance and preservation of biodiversity, formation of habitats for various species of plants and animals, including rare and species listed in the Red Book of Ukraine, as well as maintaining the maximum biological productivity of aquatic ecosystems.

The marine and coastal ecosystems of the Northwestern Black Sea region play an important role in providing recreational services. Comfortable bioclimatic conditions, a significant length of the beach area and other natural and recreational resources make it possible to speak about the prospects of the coastal zone of the North-Western Black Sea region for various forms of recreation, including thalassotherapy (treatment with a sea climate and bathing in combination with sunbathing) [72, 73].

The attractive sea and coastal landscapes of the North-Western Black Sea (NW Black Sea) region with a unique visual environment have aesthetic value. The Danube and Black Sea Biosphere Reserves, "Tuzlovsky Limans", "Kuyalnitsky" and "Dzharylgatsky" National Natural Parks, regional landscape parks and other objects and territories of the nature reserve fund can provide educational services, as they are natural scientific laboratories in which carry out research activities in the field.

The marine and coastal ecosystems of the NW Black Sea region are the habitat and source of food for numerous organisms. The role of wetlands protected by the Ramsar Convention is especially important (Chilia branch, Sasyk Lagoon, Shahany-Alibei-Burnas lakes system, Northern area of the Dniester Liman, Tylihul Lagoon, Kuhurluy etc.), which are of great importance as a habitat for waterfowl and birds living in the coastal zone, and characterized by biodiversity.

An example of the structure of the natural vegetation of a wetland is the distribution by economic plant types of the Danube Biosphere Reserve (DBR) vegetation [74, 75]. Thus, the group of food plants of the DBR (Danube Delta) includes 314 species (33.00 % of the total flora), fodder crops − 281 species (29.58 %), medicinal − 232 species (24.42 %), technical − 178 species (18.74 %), poisonous − 133 species (13.75 %), non-food economic − 77 species (7.00 %) [76].

Wetlands are an important habitat for valuable species of birds, mammals, amphibians, reptiles. The total number of water birds breeding within the DBR wetland is 25 thousand pairs, which nest mainly in reeds, floodplain forests, on small islands and peninsulas. In autumn and spring, up to 133 species of migratory birds can be found here. The migration route is mainly along the coast with resting places on bays and sandbars. The total number of migrants flying through this area every year is about 2-3 million birds. About 28 thousand birds can stay here for the winter. Species of birds from the Red Book of Ukraine that nest here are pygmy cormorant *Phalacrocorax pygmaeus*, curly pelican *Pelecanus crispus*, yellow heron *Ardeola ralloides*, white-eyed pochard *Aythya nyroca*, kentish plover *Charadrius alexandrinus*, eurasian oystercatcher *Haematopus ostralegus* [77].

The waters of the wetlands are the habitat of many species of reptiles, amphibians and fish, as well as spineless. The composition of the ichthyofauna includes mainly local, including anadromous, fish species. Shallow areas of well-heated bays are a place for spawning and growth of fry of many cyprinids and Danube herring. Among the fish listed in the Red Book of Ukraine, there are: Danube salmon *Hucho hucho ssp. hucho* (endemic subspecies), sterlet *Acipenser ruthenus*, striped ruffe *Gymnocephalus schraetser*, Black Sea beluga *Huso huso* *ponticus*, European mudminnow *Umbra krameri*, Danube streber *Zingel streber streber* and zingel *Z. zingel*. Species of spineless from the Red Book of Ukraine: dragonflies *Coenagrion lindeni* and *C. mercuriale*, molluscs *Turricaspia lincta* [78].

As supporting services, wetlands play an important role in primary production and photosynthesis, as well as a source of food, raw materials, genetic resources for medicines; they mitigate floods, protect coastlines and increase resistance to natural disasters, and also play an important role in the development of the transport system and recreational and tourist activities, in the cultural and spiritual well-being of people.

The most intensive cycle of biogenic (nutrient) substances occurs in the rivers mouths flowing into the Northwestern part of the Black Sea. These substances come from inorganic sources or are recycled from dead organisms. At the same time, many resources are now depleted for a variety of reasons: overfishing, destructive fishing practices, negative impacts from aquaculture, pollution and eutrophication, climate change, and more.

2.3 Blue economy innovative projects investment outlook

Main promoter of marine and coastal innovation in blue economy sector of Ukraine and other Black Sea countries is DOORS and Bridge project developed Black Sea Accelerator initiative.

Ukraine, in the conditions of a full-scale war, does not have the opportunity to support all companies and technological areas of development. Today, one of the priority areas is the development and implementation of information technologies that can help optimize resources and improve access to public services for citizens. Ensuring the needs of the Armed Forces of Ukraine and the civilian population in medical drugs and equipment is a vital task in today's conditions.

The total volume of investments in Ukrainian technology companies in 2022 amounted to US$842 million, which is 45 % more than in 2021. Three companies – Firefly Aerospace, Grammarly and People.ai – attracted more than 58 % of the total volume of venture investments in Ukrainian companies. According to the results of the study, in 2022, the full-scale war negatively affected the development of the startup ecosystem in Ukraine, causing a significant decrease in its positions in this area. In the global ranking for 2022, Ukraine ranked 50th (compared to 34th in 2021), ahead of Hungary and South Africa, and among European countries, our state ranked 30th, which is nine positions lower than in 2021. In 2023, Ukraine's position improved slightly – 49th among all countries in the world, ahead of its closest competitors – Hungary and Serbia.

The main principles, priorities and directions of Ukraine's innovation policy are set out in the "Strategy for the Development of the Sphere of Innovation Activity for the Period until 2030", approved by the Resolution of the Cabinet of Ministers of Ukraine dated July 10, 2019 No. 526-p., which identifies the imperfection of institutions, in particular the political, regulatory and business environment, among the main barriers to the development of innovations in Ukraine.

List of main funds supporting the development of startups and innovative projects:

- Invention Support Fund of the Ministry of Economy of Ukraine [79];
- Horizon Europe Program [80];
- Global Innovation Fund [81];
- Ukrainian startup fund [82].

In addition, it should be noted that foreign direct investment is one of the most important sources of not only financial support for domestic entrepreneurs, but also an incentive for the modernization of business processes and the potential expansion of activities based on innovative technologies.

2.4 Stakeholder groups of Ukraine's blue economy

In order to study issues related to “blue growth” in the Black Sea region, a working group was created within the framework of the DOORS project, bringing together key stakeholders of Ukraine, to work in the Multi-Actor Forum (MAF). The main stakeholders of the DOORS project in Ukraine are government and commercial organizations, civil associations, educational and research institutions.

As a result, the MAFs, local stakeholder needs were identified and innovation pathways to support Blue Growth in the region were developed. The figure 2.13 shows the main stakeholders (according to their belonging to different groups and the blue economy sectors) and their distribution according to the degree of interest and influence on the blue economy of the Black Sea.

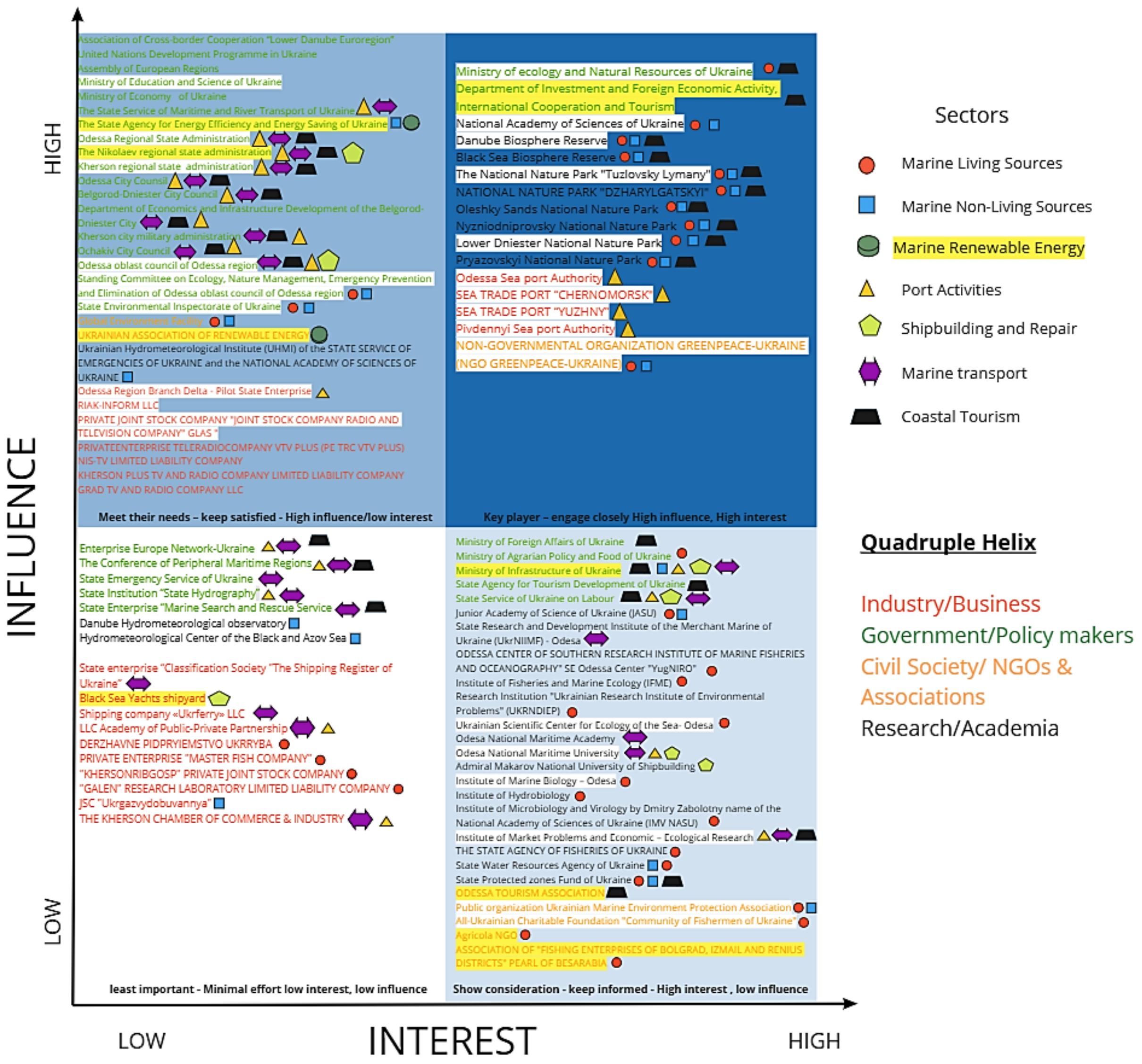

Fig. 2.13. Key stakeholders in the blue economy in Ukraine

As a result of consultations with stakeholders, priority sectors of the blue economy in Ukraine (ports activity, marine transport, capture fisheries, marine and coastal tourism, shipbuilding) in the current conditions were identified. Based on the Sustainable Development Goals and current needs, a vision for the long-term development (up to 2050) of priority sectors of the blue economy in Ukraine was developed.

CHAPTER 3: PROSPECTS FOR EMERGING SECTORS

Today, the renewable energy sector in Europe belongs to the established sectors of the economy and special attention is directed to the development of such areas of the Blue Economy as offshore wind energy. Currently, technologies for the use of offshore wind energy have become the main direction in the development of wind energy. Due to the lower water surface roughness compared to the earth's surface, the wind speed over the sea is usually 20% higher than under the same conditions over the surrounding lands. This contributes to the production of much more energy from offshore wind farms than onshore. An offshore wind turbine has a higher power factor than its onshore analogue. In addition, because the wind speed over the sea surface is relatively homogeneous with less pulsation and turbulence, it simplifies the control systems of offshore wind turbines (OWT) and reduces the wear of their blades [83].

As of June 2020, there are twenty offshore wind farms in the Baltic Sea − nine owned by Denmark, five by Germany, four by Sweden and two by Finland. The total capacity of these wind farms is about 2 GW. Expected capacity from offshore wind farms installed in the Baltic Sea is estimated at approximately 9 GW by 2030 [84].

Record increase in offshore wind power capacity in the world by 5 GW was set in 2020, as a result, the global operational capacity of offshore wind energy was approximately 33 GW, which allows to maintain the growth rate, despite the problems caused by COVID-19. Fifteen new power plants were commissioned in 2020, this means that there are now more than 160 offshore wind farms operating around the world. The UK remains the largest offshore wind energy market in the world with around 10 GW of installed offshore wind power capacity. In second place is Germany with about 8 GW and in third place in the world is China, with an installed offshore wind power capacity about 7 GW [85]. Offshore wind power growth is projected to accelerate in the coming years, reaching around 200 GW by 2030. Today, humanity is in search of new sources of energy to make the economy more sustainable, as well as the need for a transition to energy that works on the principles of Carbon-Free Technology. For the Black Sea, this is expressed in the desire for successful implementation of the program Blue Growth Accelerator, which is aimed at the introduction of innovative technologies and alternative energy sources in the energy sector of the Black Sea countries, for the development of the "Blue Economy" and the achievement of its healthy, productive and sustainable state.

3.1 Offshore wind power potential of the Black and Azov Seas

The assessment of the offshore wind power potential of the Black and Azov Seas is of considerable interest, in terms of, that the development of offshore wind energy could provide additional capacity to the energy system of Ukraine and other countries of the Black Sea region, and strengthen the transition of their national energy complexes to renewable energy sources, which will help reduce carbon dioxide emissions into the atmosphere and help to counteract climate change on the planet.

A wide range of research is devoted to the study of the wind over the Black and Azov Seas, since data on the wind regime are of extreme importance for regional oceanography. The wind directly affects the circulation and mixing of waters, heat and water balance.

Standard regular wind observations at coast stations show, that the southeastern coast of the Black Sea and the southern coast of Crimea are characterized by light winds (mean annual wind speed < 3 m/s). Gentle winds are observed in the western and northwestern parts of the Black Sea, as well as near the Kerch Strait (mean annual wind speed > 4 m/s, and at some stations > 5 m/s).

The results of observations at the North-Western Black Sea coastal meteorological stations show, that the long-term average wind speed is in the range from 4.0 m/s (Chornomorsk) to 5.5 m/s (Odessa). The highest wind speeds are observed over open areas of the sea – 6.7 m/s (Snake Island), and 7.4 m/s (Sulina).

Analysis of wind characteristics over the open sea, obtained using data from ship observations, global reanalyses of atmospheric fields (ERA-40, NCEP/NCAR, JRA), regional reanalyses with high spatial resolution [86], mean SLP fields [87], as well as NASA satellite scatterometer data [88] showed, that the obtained estimates of the spatial distribution of wind speed over the Black Sea have common features: the western part of the sea has the highest values, the zone of weak winds is typical for the southeastern part of the sea. The local wind speed maximum is situated in the northeastern part of the sea south of the Kerch Strait.

The mean annual wind speed over the Azov Sea is 4.5-5.5 m/s near the coast, and 7.5 m/s in the central part of the sea. The mean seasonal wind speed in winter is greater than in summer. Wind speed in December in the central part of the sea is 8.3 m/s, on the coastal stations is 6-7 m/s [89].

The study of the long-term changes of wind speed over the Black Sea showed that there is a clear trend towards a decrease in the second half of the 20th century. At the same time, according to [90] after 2000, wind intensification is noted in the western part of the sea. At some stations, the decrease in wind speed reaches 20-50% relative to climatic norms.

3.1.1 Wind potential assessment methodology

The main characteristic that determines the wind energy potential of the territory is the wind speed. A 10-year series of observations is sufficient to obtain stable values of the mean wind speed. The initial requirement for the deployment site of autonomous wind turbines and wind power plants is the presence of a high wind energy potential. In the first approximation, it can be characterized by the value of the mean annual wind speed ≥ 5 m/s at 10 m height [91]. An additional requirement for the site of placement of wind turbines is the absence or slight recurrence of hurricane winds ($V > 32.7$ m/s) and a small number of storm periods ($V > 20{,}8$ m/s). It should also be borne in mind that not always large values of the mean annual speed are a guarantee of high electricity generation from wind turbines. The winds of the mountain passes are unfavorable for wind energy due to the high frequency of storms.

Potential wind energy resources are the total energy of the movement of air masses moving over a given territory during the year. The most accurate assessment of potential wind resources can be obtained using the wind power density, which is the energy characteristic of the wind, depending on the frequency of wind speeds and the nature of the underlying surface in a particular site. Wind speed is a random function of time. More precisely, its description can be obtained using the Weibull distribution for flat terrain conditions [91]:

$$f(u)=\frac{\gamma}{\beta}\left(\frac{u}{\beta}\right)^{\gamma-1}\exp\left[-\left(\frac{u}{\beta}\right)^{\gamma}\right], \tag{3.1}$$

where *f(u)* is the frequency of occurrence of wind speed u, β – scaling factor (m/s), γ – the shape factor, which is describes the shape of the distribution.

The wind power density can be estimated using the formula:

$$N_e=\frac{1}{2}\rho\beta^3\Gamma\left(\frac{3}{\gamma}+1\right), \tag{3.2}$$

where *Ne* – wind power density, ρ – air density (1.226 kg/m^3), $\Gamma\left(\frac{3}{\gamma}+1\right)$ – gamma function.

The assessment of the wind energy potential of area is carried out using the criteria given in Table 3.1, which allow to allocate seven classes for the values of wind power density (*Ne*). The area suitable for accommodation of large-scale wind plants must have a wind energy class of 4 or higher [92].

Table 3.1 Classes of wind power density [92]

Wind power class		50 m height	
		Wind power density, W/m^2	Mean wind speed, m/s
1	Poor	< 200	< 5.6
2	Marginal	200-300	5.6 - 6.4
3	Fair	300-400	6.4 - 7.0
4	Good	400-500	7.0 - 7.5
5	Excellent	500-600	7.5 - 8.0
6	Outstanding	600-800	8.0 - 8.8
7	Superb	>800	> 8.8

This approach to estimating wind resources has been considered in a number of studies, has shown good results and has been used to plan the location of wind turbines.

3.1.2 Principles of design and placement of OWT

Planning an offshore wind farm requires the following information. Firstly, these are the wind characteristics in the sea. Additional data include water depth, currents, seafloor, sediment transport and wave action which cause mechanical and structural stresses on potential turbine configurations. Other factors include salinity, glaciation and the geotechnical characteristics of the seabed.

Based on the methodology described in the report «Going Global: Expanding Offshore Wind to Emerging Markets» [93], to accommodate OWT are suitable water areas that meet these conditions [94]:

1. Annual mean wind speed greater than 7 m/s at 100 m height (6.3 m/s at 50 m height), for the current performance characteristics of OWT;

2. Water depth of less than 50 m – for fixed offshore wind farms;

3. Water depth between 50 to 1000 m – for floating wind farms;

4. Less than 200 km from shore;

5. Any isolated regions < 10 km^2 were excluded;

6. Constant turbine planting densities of 3 MW per km^2 for wind speeds between 7-8 m/s and 4 MW per km^2 for wind speeds greater than 8 m/s.

Sea ice is part of the marine conditions, which in particular must be included in the design process for the support constructions of OWT. Sea ice is an important but under-researched source of loading on all types of OWT structures. The complex ice mechanics, which is influenced by many factors, introduces a serious uncertainty in the assessment of ice loads on the support structures. For example, floating and pack ice on the water surface and atmospheric icing induce the wind turbine to excessive vibrations, ice drift and hitting against the foundation might trigger structural vibrations or even damage it by exciting the tower, while structures icing will excite flapwise the blades but the main effect is felt on the tower [95]. From these considerations, it is clear that in cold climates on the high seas, ice formation should be considered as a major factor in site analysis. Ice prevention systems on blades, accurate sealing, load mitigation systems for sea ice, cold weather packages, and diagnostic tools integrated to account for ice loads effects will be a sensible part of the investment and operating costs. Accurate tools for ice risk assessing are thus necessary and the impact on current design ascertained.

3.1.3 Bathymetry of the Black and Azov Seas

In the structure of the bottom of the Black Sea stand out: shelf, continental slope and deep basin. The shelf is a direct continuation of the land, which is under the waters of the sea. The shelf has the greatest width (more than 200 km) and a significant area in the northwestern part of the Black Sea (NW Black Sea). In the NW Black Sea, most of the shelf water area has depths of up to 50 m (approximately along the line of Cape Tarkhankut − Cape Kaliakra), a significant part is located up to the 100 m isobath (approximately along the line of Cape Khersones − Cape Kaliakra), and beyond the 100-meter depth (off the coast of Romania and Bulgaria beyond the 150-meter depth) there is a concentration of the isobaths, that is, a rapid increase in depth with distance from the nearest coast. The northwestern shelf (defined within the limits from Cape Khersones to Cape Kaliakra) occupies 16 % of the Black Sea water area (68 390 km^2) and everything

0.7 % water volume (3 555 km^3). The maximum width of the shelf reaches 220 km. Near the Caucasian and Anatolian coasts, the shelf is represented by a narrow intermittent strip 2.2-15 km wide at depths of less than 100 m. The central part of the Black Sea is occupied by a deep-sea basin with depths of 2000-2200 m. The greatest depth is 2258 m. The depth of the Azov Sea is on average 7 m, reaching in the central part 13-14 m.

3.1.4 Data Source

The assessment of the wind energy potential was made on the basis of wind data placed on the website of the Global Wind Atlas [96]. This application (Global Wind Atlas) is specially designed to help identify areas with strong winds, suitable for wind turbines. As input data in the atlas were used ERA5 reanalysis data for 2008-2017 of the European Centre for Medium-Range Weather Forecasts (ECMWF) with spatial resolution 30 km. Then, using the mesoscale WRF model, had been performing downscaling of the reanalysis data, as a result, information on wind speed becomes available with a spatial resolution of 3 km. At the next stage, wind speed data is processed using a microscale modeling system (DTU Wind Energy). As a result of the simulation process, the user obtains the characteristics of the local wind climate with a grid spacing of 250 m at five heights: 10 m, 50 m, 100 m, 150 m and 200 m above the earth's surface [97]. The Global Wind Atlas presents wind speed characteristics (mean annual value, indices of interannual, seasonal and daily wind speed variability), mean annual wind power density *Ne*, and it is also possible to plot the dependence of the output power of the wind turbine generator (according to the specified user characteristics) from wind speed.

3.1.5 Wind potential

According to the Global Wind Atlas, the value of *Ne* at 50 m height changes from 70-200 W/m^2 in the southeastern part of the Black Sea to 1048 W/m^2 in the Tsemesskaya Bay. In general, the spatial distribution *Ne* over the Black Sea shows an increase from the southeast, where the annual mean wind speed at 50 m height is about 5 m/s, to the northwest, where the wind speed is about 7 m/s.

Based on the value *Ne* and the above requirements for location OWT, favorable conditions for the placement of large OWT have the following sites (Fig. 3.1, Table 3.2):

Plot 1. Shelf of the NW Black Sea. This plot is located north of the line connecting Cape Tarkhankut and Cape Kaliakra, and has a depth of less than

100 m. The entire area of the shelf is occupied by an alluvial plain, which has a very slight incline and a flat plain abrasion accumulative relief. The most leveled and gently sloping part of shallow water is the 30-40 m depth zone adjacent to the coast (more than 1/3 of the entire shelf area). Based on these characteristics, we can conclude that this zone has favorable conditions for the placement of large OWT with fixed foundation.

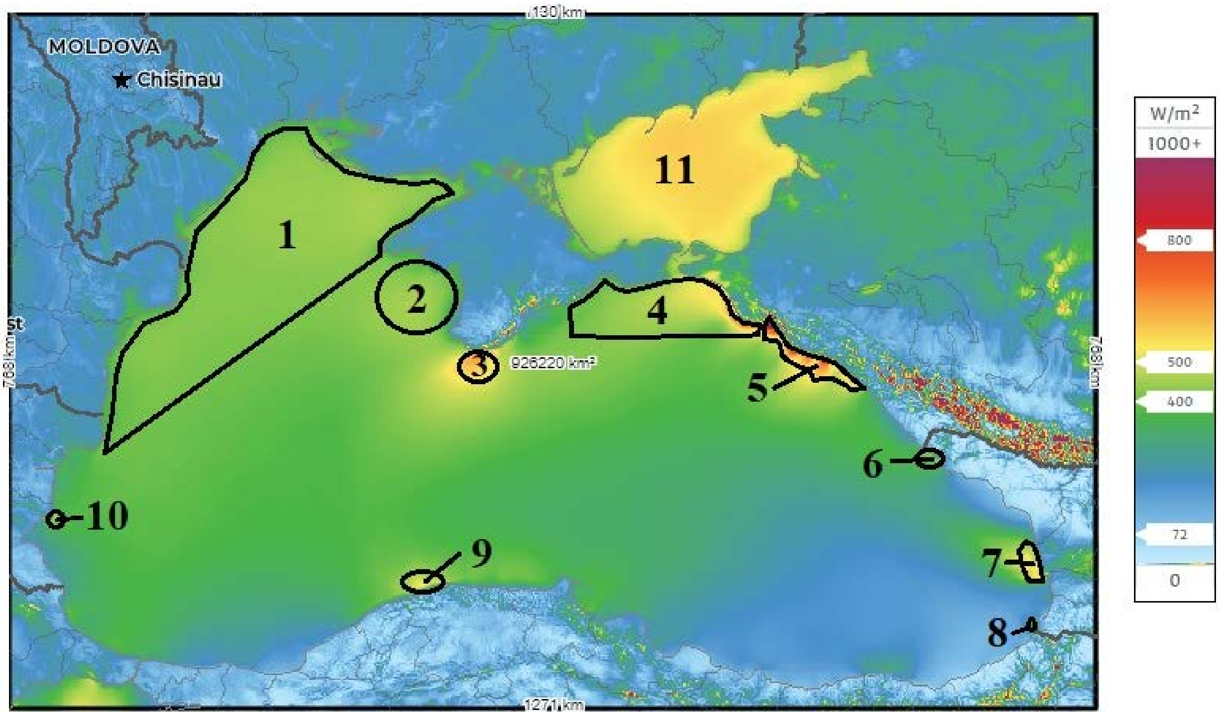

Fig. 3.1 Annual mean *Ne* (W/m^2) at 50 m height for 2008-2017 and schematic arrangement of sites with *Ne* > 400 W/m^2 and depths up to 1000 m

Plot 2. The site of Kalamitsky Bay, bounded in the north by Cape Tarkhankut, in the south by the 1000 m isobath, in the west by Cape Khersones. This site has of fourth wind power class. Most of the water area, located within the outer shelf of the Western Crimea, has depths of 50-150 m, in coastal areas (Kalamitsky Bay) depths are from 0 to 50 m. Both floating and fixed OWT can be placed on this site.

Table 3.2 Wind characteristics of sites with *Ne* > 400 W/m^2

Plot number	$\overline{V_{an}}$, m/s	$Ne_{100\%}$, W/m^2	$Ne_{10\%}$, W/m^2	Wind power class	*S*, km^2	Depth *H*, m
1	7.0-7.2	422	445	4	45000	< 50
2	6.7-6.7	421	452	4	6600	< 1000
3	7.0-7.2	555	619	5 - 6	1340	< 1000
4	7.0-7.4	460	585	4 - 5	9000	< 1000
5	6.9-7.6	588	818	5 - 7	1650	< 1000
6	5.9-6.1	420	440	4	39	200-800
7	5.8-6.2	474	540	4 - 5	1080	< 1000
8	5.0-5.4	414	450	4	20	< 1000
9	6.4-6.8	460	520	4 - 5	715	< 1000
10	6.5-6.7	420	455	4	95	15-50
11	7.6-7.7	530	568	5	33000	< 14

Notes: $\overline{V_{an}}$ – annual mean wind speed at 50 m height;
$Ne_{100\%}$ – the mean annual wind power density over the territory at 50 m height for 100 % of the area of the selected site;
$Ne_{10\%}$ – the mean annual wind power density over the territory at 50 m height for 10 % of the area of the selected site with the highest wind rates

Plot 3. located near the southern tip of the Crimean peninsula between Cape Sarych and Cape Ai-Todor. This site has of fifth wind power class. Most of the water area has depths of more than 50 m (the width of the shelf here is 30-40 km, and the width of the area with depths up to 50 m does not exceed 1.5 km). In this site, on the shelf, traces of tectonic activity appear in the form of fault lines, fracturing on the bench and block displacements. Based on the above conditions, this water area may be suitable for accommodating floating OWT.

Plot 4. Shelf between Cape Meganom and Cape Myskhako (Kerch Shelf of the Black Sea). Most of the water area has the fourth wind power class, near the coast of the Caucasus there is an increase in the average annual wind speeds, and *Ne* values reach 700 W/m^2 and more, which corresponds to the characteristics of the sixth wind class. The continental shelf in this site has the shape of a semicircle, protruding to the south, with the largest width of about 50-60 km. The angle of inclination of the continental slope is 1-3°, the development of landslide processes is noted on the slope. About half of the site (northern part) has depths of 10-50 m, making it suitable for fixed OWT. The southern half is characterized by depths of more than 50 m, which makes it possible to place floating OWT.

Plot 5. Coastal strip along the Black Sea coast of the Caucasus from Cape Myskhako to Cape Kadosh. The site has the largest reserves of wind resources with wind classes from the fifth to the highest eighth power class. Value of *Ne* in some parts of the Tsemesskaya Bay it reaches 1030 W/m^2. The site has a length of about 120 km. The width of the strip with depths up to 50 m is from 3 to 6 km, with depths up to 1000 m is from 8 to 24 km. It should be noted that between Anapa and Sukhumi i.e. along the coast of the Caucasus, the shelf is weakly expressed. In the coastal zone, the bottom slope rapidly increases, and a continental slope begins at a distance of 400-500 m.

Plot 6. The site along the Caucasian coast between Cape Konstantinovsky and Cape Pitsunda is about 20 km long and has a small area. This site corresponds to the fourth wind power class. Depth is from 200 to 800 m. In this area, the spurs of the Greater Caucasus (Gagra Range) come closest to the sea, which leads to a sharp increase in depth. The shape of the coast here forms a small curve, in the waters of which there is an underwater trough, about 5 km wide, about 9 km long and with a maximum depth of about 380-400 m. The internal relief (closed contour) of the trough is 120 m, it is separated from the continental slope by a bridge at a depth of about 260 m.This site is suitable mainly for the placement of floating OWT.

Plot 7. The site is located off the coast of Georgia between Cape Anaklia and port of Poti has wind power class 4 and 5. This area has depths of up to 700 m and is predominantly located above the zone of the continental slope, the relief of which is undergoing major complications. The bottom is streaked with numerous underwater canyons 150-200 m wide at the edge of the ledge of the continental slope, up to 300-500 m in the middle zone, and 1-1.5 km at the foot.This site is suitable mainly for the placement of floating OWT.

Plot 8. The site off the coast of Georgia near the city of Batumi has a wind power class of 4. Its length along the coast is about 8 km. The width of the shelf in this place does not exceed 5 km. According to its characteristics, the bottom in this site has similar conditions to *Plot 7*. This site is suitable mainly for the placement of floating OWT.

Plot 9. The site off the coast of Turkey between Cape Kerempe and the city of Cide. This site is a strip up to 10 km wide (limited to depths of up to 1000 m) and about 80 km long, and has a wind power class 4. The width of the shelf here is 3-4 km and it is mainly represented by a stepped abrasion and abrasion-accumulative sea plain, complicated by ridges, buttes, ledges and ravines. This site is suitable mainly for the placement of floating OWT.

Plot 10. The site off the coast of Bulgaria near Cape Emine has a wind power class of 4. This water area has depths from 15 to 50 m and is located in the zone of the Bulgarian shelf, in the inner part of which there are alongshore swells, hydro dunes and erosion troughs. Moving away from the coast, the bottom is a weakly dissected rampart-shaped hilly underwater accumulative plain, separated from the inner part by underwater hollows, well-defined at a depth of 17 to 40 m. Shallow depths in this site make it suitable for fixed OWT.

Plot 11. The water area of the Azov Sea has the fifth wind power class. The bottom of the sea is a shallow plain with a leveled relief, the maximum depth of which in the central part does not exceed 15 m. In the western part of the sea, in the area of sea banks, and in the east between the Elenina Bank and the Zhelezinskaya Bank, the flat surface of the sea bottom is disturbed by small local uplifts, which rise relative to the surrounding areas by 3-4 m. This site is suitable for placing both floating and fixed OWT.

It should be noted that for *Plot 1* (water area of NW Black Sea), *Plot 4* (Kerch Shelf of the Black Sea) and *Plot 11* (water area of the Azov Sea) from December to March, ice formation is characteristic. Moreover, if in NW Black Sea the appearance of ice in open areas of the sea does not occur every year [90], then for the Azov Sea, ice formation occurs annually, even in the mildest winters. The first appearance of ice occurs in December − early January. First of all, ice forms in bays and estuaries. The annual formation of fast ice is observed only in estuaries and bays. Complete freezing of open areas of NW Black Sea (Odessa, Tendra Spit, Karkinitsky Bay) only occurs in very severe winters. The beginning of breaking or the first shift of fast ice is usually observed in February − early March. The final cleansing of the sea is observed in March. The thickness of the ice cover in moderate winters in the NW Black Sea can reach 5-10 cm, in severe winters − 30-45 cm (smooth ice). In the Azov Sea, by the beginning of January, the average ice thickness in the Taganrog Bay reaches approximately 20-25 cm, and in the south of the sea (Kerch, Mysovoe) − 12-14 cm. The ice cover reaches its greatest thickness in late February − March and is approximately 40-50 cm in the Taganrog Bay and 20-25 cm in the southern part of the sea. In severe winters, the thickness of even landfast ice can reach 70-80 cm in the Taganrog Bay and 40-60 cm in the southern part of the sea (Kerch, Mysovoe, Temryuk). Thus, it should be noted that the factor of ice formation must be taken into account at the planning stage of OWT in these areas.

Additional load on support structures of OWT creates wind waves. So, for the west and northwest coast NW Black Sea the average annual frequency of storm waves is 3.19 % (Chornomorsk), 3.21 % (seaport "Pivdenny") and 4.47 % (Odessa port). For open sea areas of NW Black Sea the most representative are the results of observations at the wave measurement station Chersonesos lighthouse, where storm waves accounts for 22.89 %. For the NE Black Sea, the frequency of storm waves ranges from 4/47 % (Zavetnoe) до 9.75 % (Anapa). During the year, an increase in storm activity is observed in the winter months. In the coastal areas of the Azov Sea weak waves prevail, in 89-95 % of cases the height of visually observed waves at all coastal points does not exceed 0.7 m.

For modern wind turbines cut-out wind speed is 22-25 m/s. Hurricane winds can cause damage to wind turbines and their repeatability must be taken into account. Despite the fact that hurricane winds (wind speed over 25 m/s) are observed at most coastal meteorological stations of the Black Sea, their repeatability is only 0.08-0.09 %. At the stations of the Kerch Peninsula, hurricane winds are observed for 2-5 days for a period of 45-60 years, in Anapa up to 16 days for 45 years. Most often, such winds are observed in Novorossiysk, where their repeatability is 1.5 %, which is more than 50 days for 45 years.

Although offshore wind power has grown dramatically over the past few decades, there is still a lot of uncertainty surrounding how the construction and operation of these wind farms affects marine animals and the marine environment [98].

So, in the Northern Black Sea region there are unique natural ecosystems, three vast deltas of major European rivers − the Danube, the Dniester and the Dnieper, with mouth estuaries near the latter two, on the territory of which 187 species of birds nest [99]. Of these, the absolute majority − 164 species (87.7 %), are migratory, and only local populations of 23-29 bird species (12 %) are clearly sedentary, still flying in certain situations over short distances (250-500 km). The Northern Black Sea region can be conditionally considered as a certain segment of the ecotone (border) land zone with a total area of 80 000 km^2, 100 km wide, adjacent to the Black Sea (plus coastal marine area of the shelf 30 km wide). Vital for 235 bird species, seasonal transit migratory flights take place almost all year round in the region.

Despite the fact that the main direction of flight of migratory birds is 95 % along the coastline of the Black Sea, located in this area from northeast to southwest, some species of birds (white-fronted geese, common cranes, passerines) cross directly water area of the Black Sea.

At the same time, summer migrations of duck birds and waders are observed along the coast in a westerly direction in the northwestern part of the Azov Sea. Part of the birds, flying along the northern coast of the Azov Sea (15-30 %), follow to the southeast and fly along the Arabat Spit to the Caucasus.

Along the Black Sea coast of the Caucasus, there is the most massive migratory flow of birds of prey in Europe, which can be traced in the area of the city of Batumi and the lower reaches of the Chorokh River, in Georgia and Turkey (the village of Borchka) near the southeastern shores of the Black Sea.

In addition to assessing the impact of OWT on the routes of migratory birds, it is necessary to take into account what impact it will have on the inhabitants of the sea. These issues are still under study and it is necessary to focus further research on assessing the impact of the OWT operation on the Black Sea marine ecosystems before planning their deployment.

3.2 Salinity gradient power using in the Black Sea regions (in frame of the blue growth development)

The interaction of fresh and salt water can provide, in fact, unlimited, free and clean energy. The basis for the generation of such energy is the so-called salinity gradient that occurs when two types of water are mixed. After decades of work and numerous experiments, scientists have developed a way to use the energy of the salinity gradient to generate electricity. This type of electricity is also called "Blue Energy" by association with the color of mixing freshwater and salt water when rivers flow into the ocean. Places (estuaries or deltas), where rivers flow into the oceans and seas, have a truly enormous energy potential.

Salinity gradient power (SGP) is one of the new renewable energy sources. The most studied methods for obtaining SGP energy are technologies based on:

1. Reverse Electrodialysis (RED),
2. Pressure Retarded Osmosis (PRO).

Academic research, mostly done in laboratories, shows that SGP energy has a huge theoretical potential of ~1.9 TW (theoretical potential is the energy that is potentially available if all the energy dissipated in estuaries is used without any energy loss). However, the technical potential (energy that can be extracted with modern technologies, regardless of other limitations) is about 60 % of the theoretical potential and is about 980 GW [100]. In addition, the final energy output depends on local conditions, which may impose restrictions on its production, which must be taken into account when designing SGP power plants [101].

3.2.1 Working principle of SGP systems

The main approach to obtain salinity gradient energy is energy conversion, which occurs when controlled mixing (using selective membranes) of two solutions with different salt concentrations. The use of selective membranes means that mixing is limited to one of the components: either solvent (water) or solutes (dissolved salts). In the literature, several methods have been proposed for converting the energy of a salinity gradient based on the use of water-permeable membranes as in pressure-retarded osmosis [102], or based on the use of ion-selective membranes as in reverse electrodialysis [103].

Reverse Electrodialysis (RED). Direct electrodialysis has already been used quite successfully in desalination plants. Electrodialysis is a membrane separation process in which solute ions are transported across a membrane by the action of an electric field. The driving force of the process is the electric potential gradient.

Reverse electrodialysis requires two types of selective membranes: membranes that are transparent only to positive salt ions (sodium ions), and membranes that allow only negative ions to pass through (chloride ions) [104].

In a reverse electrodialysis system for power generation from a salinity gradient, as in direct electrodialysis, several cells are located between the cathode and anode, separated by membranes. The compartments between the membranes are alternately filled with a concentrated salt solution and a dilute salt solution. The salinity gradient results in a potential difference (e.g. 80-100 mV for sea water and river water) over each membrane, the so-called membrane potential. The electrical potential difference between the outer compartments of the membrane package is the sum of the potential differences across each membrane. The difference in chemical potentials causes the transfer of ions through membranes from the concentrated solution to the diluted solution. For a sodium chloride solution, sodium ions permeate through the cation-exchange membrane in the direction of the cathode, and chloride ions permeate through the anion-exchange membrane in the direction of the anode. Electro-neutrality of the solutions in both the anode compartment and cathode compartment is maintained through redox reactions at the electrodes. As a result, electrons can be transferred from anode to cathode via an external electric circuit (Fig. 3.2). This electrical current and the potential difference over the electrodes can be used to generate electrical power, when an external load or energy onsumer (e.g., a light bulb) is included in the circuit [103].

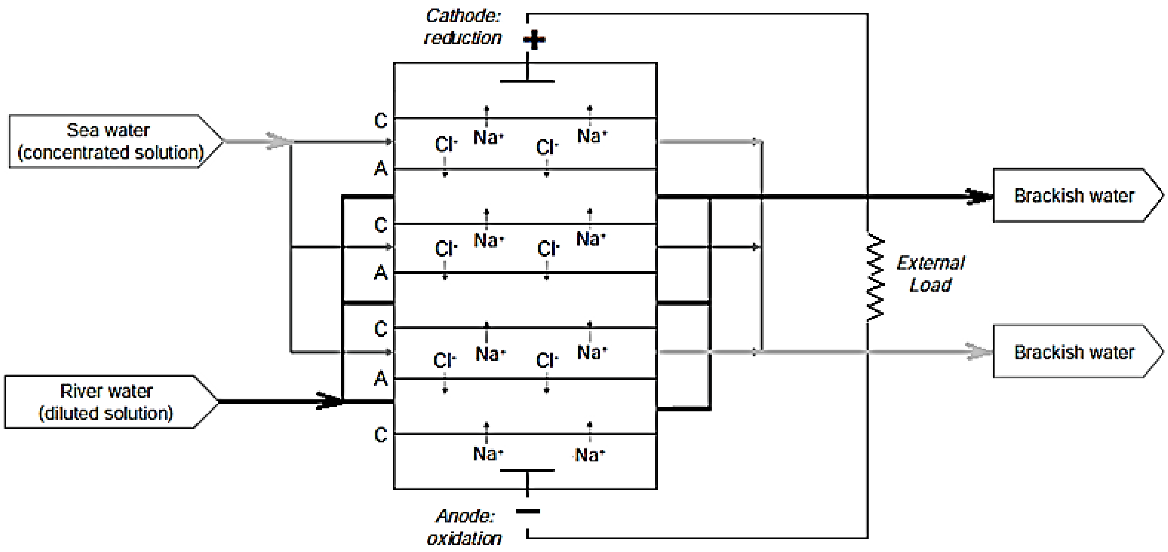

Fig. 3.2 Conceptual scheme of salinity-gradient energy produced by reverse electrodialysis (C is cation-exchange membrane, A is anion-exchange membrane)

Pressure Retarded Osmosis (PRO). The energy released by mixing fresh and salt water can be easily used. This is explained by the effect of osmosis, hence the name "osmotic energy". Osmosis is the transport of water across a semi-permeable membrane from a solution with a higher chemical potential (i.e. lower osmotic pressure or lower salt concentration) it's usually called "feed solution" to a solution with a lower chemical potential (i.e. higher osmotic pressure or higher salt concentration) – called "draw solution". This semi-permeable membrane allows the feed solution to pass by discarding solute molecules or ions.

If we separate two solutions with different concentrations by a semi-permeable partition (membrane) that allows molecules of feed solution to pass through, but preventing the transition of particles of draw solution, there will be a spontaneous transition (the system spontaneously tends to move into a prefect mixture) feed solution through the membrane from feed solution into a more concentrated draw solution. To achieve the maximum value of the entropy of the system, salt ions tend to be evenly distributed throughout the volume of the solution. As a result of the diffusion water molecules from dilute solution (*A*) into concentration solution (*B*), the total volume of the *B* will increase and the level rises until a specific pressure head is reached which counteracts the diffusion of the water molecules from *A* into *B*. This pressure is called osmotic pressure π of the solution *B*.

The osmotic properties of a solution are quantitatively characterized by the value of the osmotic pressure. Osmotic pressure is the pressure that a feed solution exerts on a semi-permeable membrane when moving from an area with a lower concentration of solute to an area of higher concentration.

In a PRO system (Fig. 3.3), the less concentrated solution flows towards the more concentrated solution due to the positive osmotic pressure difference as long as this difference remains greater than the hydrostatic pressure difference ΔP. It is by this principle that osmotic power is produced. For stable energy production, the salt water side must be maintained at a constant pressure and concentration while the feed solution provides a constant flow through the membranes, increasing the volume flow on the salt water side.

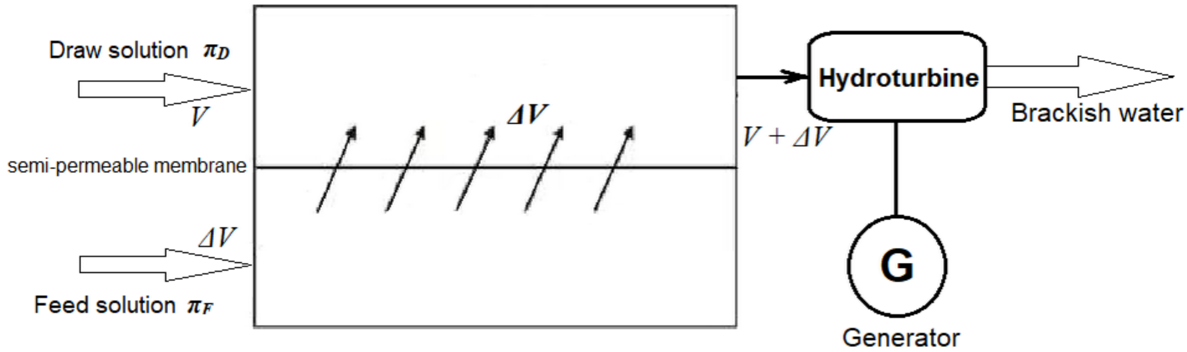

Fig. 3.3 Conceptual scheme of salinity-gradient energy produced by pressure-retarded osmosis process

The transport of water from the low-pressure diluted solution to the high-pressure concentrated solution results in a pressurization of the volume of transported water. The volume of pressurized water transported can be used to generate electrical power in a turbine [103]. It is known from experience that the pressure head between 0.5 molar seawater (equivalent to 30 ‰ salinity) and fresh water (river water) is about 24 atm [105]. This pressure is equivalent to a 240 m water head.

3.2.2 An assessment method of the net maximum theoretical power in PRO process

PRO process and osmotic power calculation method are described in more detail in [106, 107]. We will only give the basic equations with which we calculated the maximum theoretical power. As mentioned in 1, the main driving force in PRO systems is the difference in osmotic pressure in solutions of different concentrations separated by a membrane. The osmotic pressure π of any solution can be calculated using the van't Hoff equation

$$\pi = icRT \tag{3.3}$$

where c – the molar concentration ($mol \cdot L^{-1}$), R – the universal gas constant (8,31441 $N \cdot m \cdot mol^{-1} \cdot K^{-1}$), T – the absolute temperature (K), i – the number of osmotically active particles in the solution, equal

$$i = 1 + \alpha(v - 1),$$

where α − the degree of dissociation, v − the stoichiometric coefficient of dissociation reaction (for NaCl α = 1 and v = 2, thus i = 2).

The resulting unit for π in the equation (3.3) is kPa. For example, for sea water, where the concentration NaCl is 30-40 ‰ (or approximately 30-40 $g \cdot L^{-1}$, or from 0,51 to 0,68 $mol \cdot L^{-1}$), osmotic pressure is between 25 and 33 bar at a temperature 25 °C.

The potential flux through the membrane is calculated as a function of the difference in osmotic pressure between the two solutions (Δπ, in bar), the difference of hydrostatic pressure (ΔP, in bar),) and the intrinsic water permeability coefficient of the membrane (A, typically in $L \cdot m^{-2} \cdot h^{-1} \cdot bar^{-1}$)

$$J = A(\Delta\pi - \Delta P) \tag{3.4}$$

where J − the water flux (typically in $L \cdot m^{-2} \cdot h^{-1}$), $\Delta\pi = \pi_D - \pi_F$, where π_D − the osmotic pressure in the draw solution, π_F − the osmotic pressure in the feed solution, $\Delta P = P_D - P_F$, respectively.

A concentrated solution (draw solution) with a volume V and with osmotic pressure π_D is pumped into the installation at hydraulic pressure P_D. The power input is given by the product of the volume flow V and the input hydraulic pressure P_D. At the same time, less concentrated water (feed solution) enters the permeator on the other side of the membrane module at osmotic and hydraulic pressures that are low in comparison to these quantities on the concentrated side. Water permeates the membrane from the less concentrated side to the more concentrated side at a rate ΔV (note $\Delta V = J \cdot Am$, where Am – membrane area and J is the water flux from (3.4)) and acquires a pressure P_D. The mixture of the feed and draw solutions creates a new solution of brackish water, with much lower osmotic pressure. The brackish water (volume $V + \Delta V$) enters a hydroturbine in which the hydraulic pressure P_D is reduced to zero, as it delivers power of magnitude $P_D\,(V + \Delta V)$.

The maximum net power (theoretical) W_{net}^{max}, which can be produced according to the ideal PRO scheme, is

$$W_{net}^{max} = P_D(V + \Delta V) - P_D V = P_D \Delta V, \tag{3.5}$$

where $P_D{\cdot}\Delta V$ – the net power.

It should be noted that the above scheme is idealized, since this net power is achieved under the condition of no energy losses and 100 % mechanical efficiency for all system components. This scheme also assumes that the feed solution enters the system by gravity.

The ideal operating pressure P_D for maximum power output is half the osmotic pressure $\Delta\pi$ [107]. Therefore, for example, for the river-sea PRO scheme, where the osmotic pressure difference $\Delta\pi$ is about 26 bar, the ideal operating pressure P_D would be 13 bar, and the maximum useful output power – 1,3 MW per 1 $m^3{\cdot}s^{-1}$ of water (solution) passing through the membrane.

As can be seen from (3.5), maximum net theoretical power $P_D{\cdot}\Delta V$ does not depend on the volume of more salty draw solution *V*, but depends only on operating pressure P_D and water flow through the membrane *J*. Considering that $\Delta V = J{\cdot}Am$, then we can conclude that the power is essentially a function of the type of membrane and the osmotic pressure difference $\Delta\pi$, as shown in the equation (3.4).

3.2.3 Estimates of performance and cost of SGP systems

Theoretically available amount of energy released when mixing 1 m^3 of sea water (0.5 mol/l NaCl solution) and 1 m^3 of river water (0.01 mol/l NaCl solution) both at a temperature of 293 K is 1.4 MJ. According to estimates [108] made for the Mississippi River, its theoretical energy potential (with an average discharge of over 17,000 m^3/s) is 40 GW at an energy density of 2.3 MJ per m^3 of river water. It is assumed that river water is mixed with "endless" cubic meters of sea water. To estimate the potential in a first approximation this assumption can be justified: the available discharge of river water is indeed a limiting source, while the source of sea water can be considered as infinitely available. However, it is clear that this value is highly theoretical, since it does not take into account the effect of water withdrawal on salinity at the point of withdrawal into the sea, as well as on salinity gradients at the very mouth of the river.

As the concentration of NaCl in water increases, the theoretically available amount of energy increases. So, when mixing 1 m^3 of saturated brine (5 mol/l NaCl solution) and 1 m^3 of sea water (0.5 mol/l NaCl) at 293 K is 10 MJ. An example is the planned replenishment of the Dead Sea with sea water from either the Mediterranean or the Red Sea [109], to compensate of evaporation of 3 million m^3/day (although the mineral content of the Dead Sea is very different from normal sea water). At the same time, an elevation difference of 400 m is supposed to be used to generate hydroelectric power from falling sea water, and a salinity gradient is supposed to be used to generate SGP energy. It is assumed that an energy density is 10 MJ per m^3 of sea water, the energy potential under such conditions of the salinity gradient can be 350 MW, of which, according to, it is technically possible to convert 130 MW into electricity [103].

The greater the salinity gradient of the waters used, the greater the energy produced. So, in [110] salinity of sea and river water was assumed to be constant and equal to 37 g/kg and 0.1 g/kg, respectively. It was shown that with an increase in the salinity of sea water by 1 g/l, the useful power increases by 3.9 %. In the case of an increase in freshwater salinity by 1 g/l, the value of useful power decreases by 15.8 %. Reducing the salinity of sea water by 1 g/l leads to a decrease in useful power by 5.3 %. Also, the release of energy is influenced by the temperature of the water. The higher its value, the more SGP energy is released, so with an increase in temperature of both fresh and salt water by 1 °C, the amount of useful power increases by 0.6 %, while a decrease in temperature by 1 °C will lead to a decrease in energy by 0.6 %.

With an increase in the concentration in a salt solution, the theoretically available amount of energy increases, which can be extracted by mixing solutions. Therefore, in a number of studies [111-114], for the generation of SGP energy, it is proposed to consider preferably the option in which sea water and hypersaline solution are mixed. The source of such a highly concentrated brine can be lake waters with high salinity or saline groundwater, for example, when extracting of coal seam gas, the need to ‘dewater’ coal seams to depressurise the gas results in large volumes of produced water, which usually has large quantities of salts [115]. A salinity ratio of 30:1 is optimal for energy production using RED [116].

An important element of SGP systems, which affects the productivity and cost of generated energy (both PRO and RED) are membranes. The current value of net power density (which considers the membrane potential, resistance and the power required to pump the water) of membranes is a maximum of 2.7 W/m^2, but recent laboratory experiments have achieved a value of 14.4 W/m^2 (for the PRO process). Changing the cell design can increase the calculated net power density close to 20 W/m^2. However, power density is not the only measure of performance. The design of the entire facility, including the circulation of large quantities of water within the plant, determines its performance [117].

In November 2009 in the Tofte, for the first time in the world a pilot PRO power plant was officially opened by the Norwegian company Statkraft. This project used 2000 m^2 of flatsheet membranes and it technically could produce 10 kW, although the actual production was around 5 kW. In 2014, the project was closed due to the lack of long-term financial support mechanisms from investors. The company continued to study and analyze the results obtained during the operation of the power plant.

Besides Statkraft, today in Canada, Singapore and South Korea realize other initiatives to test autonomous power generation with PRO systems. These projects are in the early stages of development, aiming to scale up installations and power generation [117].

In 2003 in the Netherlands a study of power generation based on RED technology was initiated. In 2005 REDStack with Frisia, a European Salt company, 5 kW RED pilot project was started. Based on this first 5 kW pilot, REDStack and Fujifilm started a follow-up a 50 kW pilot project, located on the sea defense site and major causeway called the 'Afsluitdijk'. Work on the 50 kW pilot project has been completed and was officially opened on 11 October 2013. In the longer-term there are plans up to 200 MW for an extended installation at the same location. Statkraft did not release detailed numbers, but in their projections they aimed to produce electricity at a retail price of 65 to 125 USD per MWh [117].

Studies show that the generation of electricity from 3,000,000 m^3/day ("moderate" consumption) of river water when interacting with sea water based on PRO technology is 22,300 kW [118]. This PRO electricity generation cost data was largely based on data from a power plant in Yuma, Arizona [119], where the unit cost was 1,000 USD per m^3/day.

With the exception of cost estimates for existing projects (which reflect pilot plants), there are few reliable estimates of the cost of energy received based on PRO and RED technologies. Estimates of the cost of a kilowatt-hour of electricity generated from SGP have shown that the price ranges from 0.11 EUR/kWh to 0.22 EUR/kWh, the difference depends on the location; arrives at a range of EUR 0.28/kWh for standalone power generation down to EUR 0.11/kWh for an installation that uses the brine from a desalination plant, or other production processes that emit highly saline waters [117]. The values in Table 3.3 show several advantages of SGP over other energy sources.

Table 3.3 Comparison of SGP with other energy sources [101]

	GHGs emissions, gCO_2e/kW	**Price of generated electricity, USD/kW**	**EROI**	**Availability of renewable sources**	**Efficiency of energy conversion, %**
Photovoltaic	90	0.24	1.6-6.8	Dependent	4-22
Wind	25	0.07	18	Dependent	24-54
Hydro	41	0.05	> 100	Always available	> 90
Geothermal	170	0.07	n/a	Dependent	10-20
Coal	1004	0.042	80	Non-renewable	32-45
Gas	543	0.048	10	Non-renewable	45-53
SGP (RED)	< 10	0.10	7	Always available. But not in non-coastal countries	50-70
SGP (PRO)	< 10	0,065-0,13; with subsidies 0,05-0,06	6-7	Always available. But not in non-coastal countries	40

The main economic barrier is membrane costs, which represent 50-80 % of total capital costs. Among the problems associated with the operation of SGP installations are [117]:

1. *Bio-fouling*. Due to the presence of organic matter in sea water and freshwater, bio-fouling is a major problem for both PRO and RED installations. The reason is the fouling of the membranes, which leads to a decrease in energy production. To date, there is no satisfactory low-cost solution to this problem.

2. *Environmental and ecological aspects*. Close to power plants areas of turbulence or recirculation may occur, which increases the risk to inhabitants. To avoid this, and to reduce this effect at the point of water intake, the design of the installation must be adapted taking into account hydrodynamics.

3. *Sector development and supply systems*. One of the main tasks of the sector is the timely development of specialized infrastructure and equipment. There are currently only a limited number of companies manufacturing specialized membranes and other plant parts such as stacks or modules. For scaling will require a large number of specialized consumables.

Among the advantages the following can be distinguished:

1. *Environmental and ecological aspects.* The impact of SGP plants on the environment is minimal, which ensures the preservation of the estuaries and rivers

ecological conditions. In this process does not consume water or salt, and the installations can be located underground or in low buildings. Mono nitrogen oxides (NOX), carbon monoxide (CO) or carbon dioxide (CO_2) emissions are absent, and the installations are not important sources of noise.

In addition, hybrid SGP energy generation processes can be used to recover energy from high salinity waste streams. This can be, for example, brine from desalination or salt extraction, as well as wastewater from sewage treatment plants. Using saline wastewater as a source has important environmental benefits as it dilutes saline wastewater streams simultaneously generating renewable electricity. For example, within the European REApower project, an experiment was developed that later became a pilot project for the generation of electricity using sea water and low salinity wastewater.

In terms of overall commercialization, the technology will greatly benefit from an increase in the number of industrial parties and companies with experience in efficiently scaling up the latest developments. The first steps towards such increased participation have already been taken in a number of pilot projects in Europe, Asia and North America / Canada. This is of course in addition to more public engagement because this technology is not well known [117].

3.2.4 Selection of a site for the location of the SGP plant

Most suitable for placing SGP plant are the river mouths. However, not every river mouth is suitable for this, since river and sea water should be available at a short distance in order to reduce the cost of transporting water and the associated costs. Favorable conditions are stratified river mouths, which have significant vertical salinity gradients due to the penetration of sea water close to the bottom in the estuarine zone. If freshwater and seawater intakes are located in the site of the greatest stratification of the estuary, freshwater can be extracted near the surface, while seawater is taken in the nearest coordinate near the river bottom. This configuration significantly reduces the distance between two water intake points and therefore the energy required to transport water to the power plant. However, finding the zone of maximum stratification is not easy due to the inherent variability of flows at the river mouth.

In the methodology proposed in [110] shown that when assessing of the SGP plant location conditions use data about average salinity along the estuary during the dry season of the average climatic year near the surface and at 10 m depth, on which the salinity profile is built.

As it was said above, an important problem is membrane fouling. Therefore, it is necessary to analyze the content of organic matter in the riverbed.

Then, the costs for the production and transmission of electricity are estimated by calculating the net power of the SGP installation at different points of intake water located in the river estuarine zone. Comparison of the results makes it possible to evaluate the advantages between higher electricity generation when water intakes are distant from each other and the costs associated with pumping water over these distances.

From the point of view of the theoretically available energy that can be extracted by mixing solutions, it is preferable to consider a scheme in which sea water and hypersaline solution are mixed. This gives significant salinity gradients and, consequently, the largest energy released in this case. So, in a number of studies [111-114] large-scale water systems with high salinity gradients are considered. The waters of the Caspian, Mediterranean, Atlantic, Indian oceans, etc., with salinity from < 10 g/l up to 45 g/l, suggested to be mixed with highly saline waters of lakes with salinity of 300-348 g/l, as well as use dried lakes with a salt bottom, which can be a source of a highly concentrated solution when filled with water.

The idea is based on the pumping of sea water into a salt lake and a decrease in the volume of water in the lake due to evaporation, which leads to an increase in the concentration of salts in the water. Then, this hyper-concentrated solution would then be paired with sea water (less concentrated) in a SGP plant. So, according to [112], Lake Torrens (South Australia) could be used as a source of hyperconcentrated salt water for osmotic power generation. The lake's area is 5700 km^2 and it remains dry during almost the entire year. In this region the mean annual rainfall is less than 250 mm, and annual potential evaporation is around 3,500 mm. Kelada [112] proposes to expand the seawater canal, connecting the lake and the Spencer Gulf, located about 80 km south of the southern end of the lake, to a capacity of 1000 m^3/s, to fill the lake with sea water. Calculations show that Lake Torrens can provide brine with a salt concentration of 320 g/l, which can be used as a draw solution in an osmotic power plant when paired with the diverted sea water, with 3.5% salt concentration. Thus, this configuration proposed for Torrens Lake can generate up to 2.6 GW of energy for a seawater flow rate 225 m^3/s.

It should be noted that membranes for use in sea water and hypersaline water circuits are currently a problem. According to She et al. [120], and Kim and Elimelech [121], maximum water fluxes and projected optimum power densities for sea water and hypersaline water schemes are difficult to obtain in a laboratory setting with commercially available membranes due to their inability to withstand high pressures. Loeb [122] already suggested that hypersaline lakes such as the Dead Sea and the Great Salt Lake could be used as sources of draw solution to generate osmotic power if membranes could be manufactured for this purpose.

At the same time, the use of the sea water and hypersaline solution from salt lakes scheme will not affect freshwater resources, unlike the river water and sea water scheme. In addition, energy production will not be limited by the availability of feed solution, because there is a lot and practically unlimited of the sea water. This is different from a freshwater and sea water system, which will require large volumes of freshwater, which is not always available in such quantities, especially in areas with high demand for water, where the resource must be shared with other water users, some of them with a higher priority than electricity generation.

3.2.5 Salinity and temperature regime of the Black Sea and limans of the north-western Black Sea coast

Based on the above conditions and the proposed examples, we will further consider the haline conditions in the Black Sea and coastal water bodies of the northwestern Black Sea region from the point of view of the presence of sufficient values of the salinity gradient.

The salinity field in the Black Sea is formed by the balance of freshwater and water exchange through the Bosporus. The excess of freshwater input with streamflow and precipitation over evaporation leads to a relatively low salt content compared to most marine basins. The surface layer salinity of the Black Sea is on average 17.8 ‰, which is almost half the salinity of the surface waters of the World Ocean. The average salinity throughout the Black Sea in the layer 0-300 m is 20.2 ‰. Specific values of water salinity in the Black Sea are in a fairly wide range from 0 to 37 ‰. Isolated volumes of freshwater in the surface layer are observed near river mouths during flood periods. Highly saline Mediterranean waters (34-37 ‰) penetrate in the sea along the bottom of the Bosphorus Submarine Canyon – a continuation of the Bosphorus Strait [90].

A characteristic feature of the vertical haline structure of the sea is the presence of two haloclines: seasonal in the 0-30 m layer and permanent (main) in the 50-100 m layer. The seasonal halocline is well pronounced in the period from April to September, the maximum vertical salinity gradient gradually deepens during this period from the sea surface to a 20 m depth, the gradient values are on average 0,02-0,05 $‰ \cdot m^{-1}$, in the northwestern part of the sea can reach 2 $‰ \cdot m^{-1}$.

The maximum vertical gradient in the permanent halocline is located at 50-70 m depths, the gradient values are in the range 0,03-0,06 ‰·m^{-1}, maximums may exceed 0,1 ‰·m^{-1} [123].

The average monthly water temperatures in winter off the northern coast of the Karkinitsky Bay are 0,0-2,0 °C, in the Odessa Bay – 0,9-1,1 °C and near the mouth of the Danube – 0,3-2,2 °C. In late March – early April, the water temperature rises rapidly and reaches a maximum in July – August, when the average monthly temperatures are 20-25 °C [124].

In the northwestern Black Sea region, along the coast between the Danube and Dnieper rivers, there are 21 limans (lagoons) (Fig. 3.4).

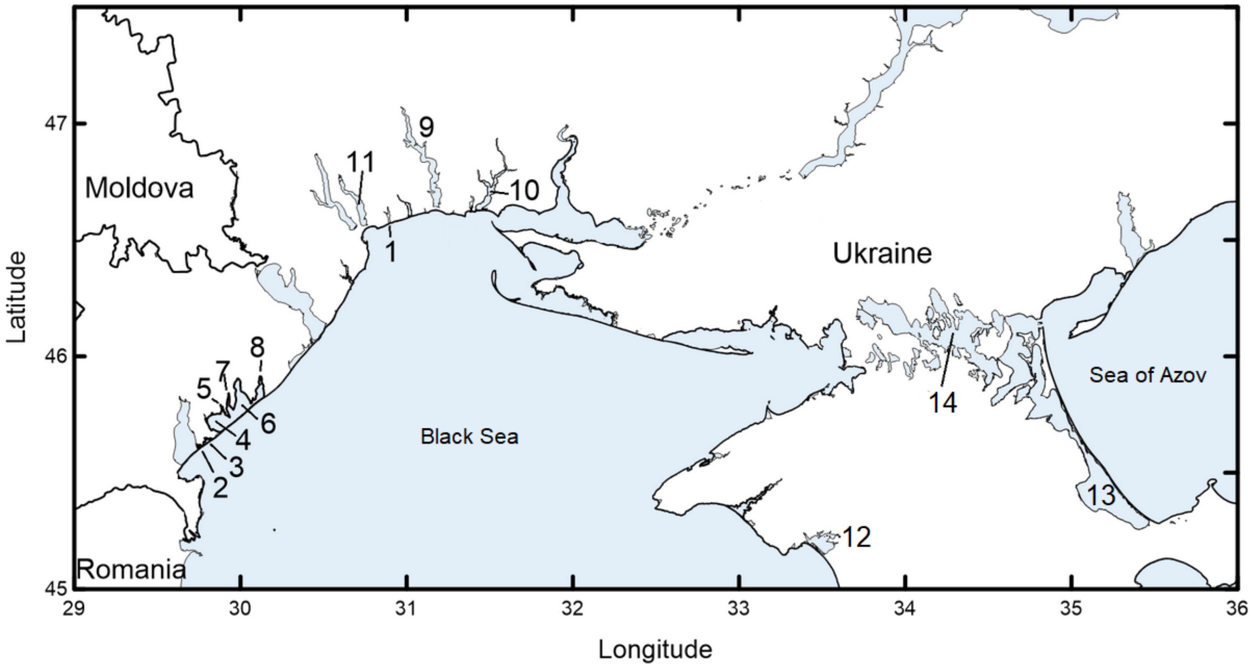

Fig. 3.4 Polyhaline and hyperhaline limans and reservoirs of the northwestern Black Sea region: 1 – Big Adzhalyksky (Dafinivsky), 2 – Dzhantsheysky, 3 – Maly Sasyk, 4 – Shagany, 5 – Karachaus, 6 – Alibey, 7 – Hadzhider, 8 – Burnas, 9 – Tiligulsky, 10 – Berezanskyi, 11 – Kuialnyk, 12 – Sasyk-Sivash, 13 – eastern part of Sivash, 14 – western part of Sivash

The hydrological regime of the limans of the northwestern Black Sea region is characterized by extremely low water content. Limans, which, due to historical circumstances, are deprived of the possibility of free water exchange with the sea through natural or artificial channels in dry years, can significantly dry out and "salinize". The polyhaline type (salinity 15-45 ‰) includes limans: Big Adzhalyksky (Dafinivsky), Dzhantsheysky, Maly Sasyk, Shagany, Karachaus, Alibey, Hadzhider, Curudiol, Burnas, Tiligulsky, Berezanskyi. To the hyperhaline type (salinity > 45 ‰) relate – Kuialnyk Liman, southern part of Sasyk-Sivash, Sivash. However, salinity in most of the listed limans experiences significant changes during the year, during which salinity decreases to values less than 15 ‰. Some limans may belong to a different type of salinity depending on the water content of the year and the inflow of sea water into their water area.

The main components of the water balance of the northwestern Black Sea region limans are: inflow of surface waters into the reservoir, including the inflow of river waters and overland flow from the adjacent territory; water supply due to precipitation falling on the water surface; water loss due to evaporation; water exchange of limans with the sea; groundwater inflow and water loss for filtration into the banks (in the long-term context, this component of the water balance can be ignored in calculations). The increase in the trend of average annual air temperatures after the 1950s led to an increase in the growth of positive evaporation anomalies.

3.2.6 Objects potentially suitable for SGP power plants operation

Let's consider which water bodies have the necessary characteristics, and which objects can be considered as potentially attractive for the placement of SGP power plants.

As you can see, the salinity of the Black Sea waters does not correspond to the values necessary to use them as a draw solution in SGP installations due to its low salinity (up to 17.0-18.0 ‰ at the surface). Therefore, in this case, it is necessary to look for other sources with a salinity of 30.0-35.0 ‰ and more. Such objects include the following limans:

1. *Shagany Liman* and *Alibey Liman* are part of the Tuzly Limans group, which is located in the south of the Odessa region in the middle part of the Danube-Dniester interfluve. The average area of the Shagany Liman is 71 km^2, and the area of the Alibey Liman is 98 km^2. This complex of connected limans is separated from the sea by a sandbar more than 25 km long. The width of the sandbar ranges from 50 to 400 m, and it height above the water's edge – from 1.5 to 3 m. The water temperature in summer reaches 30 °C, in winter it drops to 0 °C.

The water balance of the group of Tuzly Limans (Fig. 3.4, number 2-8) mainly depends from the characteristics and intensity of water exchange with the sea. In its incoming part, the share of precipitation is 30-40 %, and the inflow of sea water is 60-70 %. The remaining 10 % is the overland flow and the filtration of sea water through the sand bar and partially the outflow of water into the sea through channels during offshore winds. The expenditure component of the Tuzly Limans water balance is mainly represented by evaporation (90-100 %), which can exceed 1000 mm/year, as a result of which the water in the limans becomes saline. In the years when the canals do not work, the water balance of the limans is negative. Model calculations showed [123], that in the average water year during the winter-autumn period the incoming component of the water balance exceeds the outgoing component by 39.1 million m^3. Therefore, when the channels are opened in May, there will be an outflow of liman water into the sea. From June to September, evaporation from the surface of the reservoir is 81.9 million m^3, and the inflow of water due to precipitation (91.1 % of the incoming part of the balance) and overland flow (6.9 %) is only 27.9 million m^3, i.e. water deficit in limans is 44 million m^3.

The salinity of water in limans is subject to significant inter-annual and intra-annual fluctuations. It changes over the years and seasons. In 1868-1869 the Tuzly Limans completely lost contact with the sea, dried up and turned into marshy solonetz soils, which led to an ecological disaster and the almost complete disappearance of water bodies. At the beginning of the 20th century, as a result of the restoration of the connection between the limans and the sea, the salinity of the water decreased. In 1992-1993 in the absence of communication with the sea, the salinity of the limans again increased to 34.0 ‰. Its decrease to 22.0-26.0 ‰ occurred only in 1995 after the opening of two canals for launching fish into the liman from the sea. In 2000, the channels did not work, and salinity already exceeded 26.0-30.0 ‰ in spring, and in autumn 2002, in conditions of complete isolation of limans, it reached 52.5 ‰ [124]. So, according to the results of the expedition in the summer of 2008 [125] in the Shagany Liman, salinity on the water surface was in a wide range, from 45.6 ‰ to 53.1 ‰. The maximum salinity at the bottom was 54.3 ‰, and the minimum was 45.6 ‰. In the Alibey Liman in the surface horizon, the maximum salinity was 54.3 ‰. The average value was 52.4 ‰, which is significantly higher than in the Shagany Liman (47.9 ‰). In the near-bottom horizon of the Alibey Liman, the maximum salinity value coincides with the maximum on the surface and is 54.3 ‰, the minimum is 47.8 ‰. The average salinity at the bottom in Alibey is 52.3 ‰.

In years when the group of Tuzly Limans have a connection with the sea, and the volumes of precipitation and overland flow are quite large, the salinity of the waters decreases. It is always minimal in spring, and maximal in autumn, before the canals open. The recent regime of fishery exploitation of the Tuzly Limans implies the mandatory opening of canals in the spring − for the admission of mullet fry from the sea into the reservoir, and in autumn − for catching mullet in canals when it leaves the limans into the sea. During the summer period (June-September), the estuaries are isolated from the sea to prevent the mullet go to sea. Since water exchange with the open sea through connecting canals in the sandbar, aimed at replenishing the waters of the liman with sea water, plays an important role in stabilizing the hydrological and hydrochemical regime of limans and their ecological state, the intake of saline water for the operation of the SGP plant and the discharge back into the liman of brackish water would help maintain the steady state of the liman.

As a source of freshwater the waters of the Danube River can be used, which is removed from the southwestern shore of the Shagany Liman at a distance of 37 km, and if we take into account the canal connecting the Danube and Sasyk Lake – at a distance of 30 km.

2. *Kuialnyk Liman* is a closed body of water in the northwestern Black Sea region, the inflow of surface water into which is constantly decreasing. Kuialnyk Liman can be attributed to water bodies with extremely high salinity. Its area varies from 25 to 60 km^2, the average depth does not exceed 0.30-1.0 m. The liman is located in the mouth section of the Bolshoy Kuyalnik River and is separated from the sea by a sandbar. The water level in the liman is usually 5 m below the Black Sea level, but it, like the water salinity, changes regularly. In some years, salt precipitates to the bottom of the liman. Recently, due to the regulation of the Bolshoy Kuyalnik River the water area of the Kuialnyk Liman has decreased by almost three times and now is 2,240 km^2.

The hydrological and hydrochemical regime of the Kuialnyk Liman is determined by natural and anthropogenic factors: the Bolshoy Kuyalnik streamflow, inflow of fresh and brackish waters from reservoirs and streams of the liman sandbar and adjacent territories, atmospheric precipitation and evaporation, filtration of sea water through the sandbar, overland flow and groundwater flow, development of hydrobiological processes within the liman. The natural inflow of water into the liman is carried out due to precipitation, overland and groundwater flow, water filtration through the sandbar, wherein the last two components do not reach 1 % of the total inflow [126]. In 2011-2012 according to [127] streamflow was about 2 million m^3/year. The drainage area of the Bolshoy Kuyalnik River is 1780 km^2, and the water area of liman is 450 km^2. Salinity of brine in October in the southern part of the Kuialnyk Liman in 1997-2012 ranged from 112.0 ‰ in 2004 to 319.0 ‰ in 2011. In 2008-2014 the average monthly salinity was 200.0-320.0 ‰, and the absolute values in the summer-autumn period reached 399.9 ‰ in the shallow northern part of the liman [128].

After the completion of the project to restore the Kuialnyk Liman, in which it was connected to the sea by a pipeline (the distance to the sea is about 2 km) [129], since 2014, to restore the water regime of the liman, annually (December–April) about 10 million m^3 of sea water are let in by gravity, as a result, the mineralization of brine in the liman decreased from more than 300.0 ‰ to 240.0 ‰. Together with water, more than 350 thousand tons of salts were brought into the liman [130]. Thus, even the undertaken replenishment of the liman with sea water in the winter-spring (December-April) months of 2014-2016 allowed only to maintain the state of the liman at the level of recent years [131]. As possible alternative options for restoring the required level and salinity of the Kuialnyk Liman water, the option of supplying water from the Dniester River, located at a distance of 40-50 km, and drinking water from the ‘Infox’ LLC (‘Infoxvodokanal’) was considered [132]. However, after a comprehensive review, it was concluded that the replenishment of the Kuialnyk Liman with drinking water in modern conditions is not economically feasible, due to its high cost.

Thus, this object is potentially suitable for placing SGP plant operating on the principle of mixing sea water and a hypersaline solution of the Kuialnyk Liman waters.

3. *Sasyk-Sivash Lake* is located in the western part of the Crimea and belongs to the Yevpatoria group of salt lakes, formed from shallow sea bays and lagoons of the Kalamitsky Bay, separated from it by narrow sandbars. The lake area is approximately 75.3 km^2. The drainage area is about 1064 km^2. In 1962, in order to increase the salt concentration and optimize the receipt of raw materials for a chemical plant, from Cape Krasny, located on the eastern shore of the lake to the outskirts of Yevpatoria, a dam about 9 km long was built, dividing Sasyk-Sivash Lake into the northern one, subject to freshwater runoff, and the southern part. After the construction of the dam, two completely different reservoirs were formed. The northern part is connected to the Karaymskyi Liman, which, in turn, is connected to the Kalamitsky Bay of the Black Sea. According to the data [133], water salinity in the northern part ranges from 6.6 to 11.1 ‰ and depends mainly on the wind regime and waves. The southern part is drainless hypersalty with salinity up to 316.1 ‰. In areas located at some distance from the dam in the southern part of the lake and directly at the dam, salinity is lower and on the surface is 184.4-272.8 ‰. Sasyk-Sivash Lake, as well as the Kuialnyk Liman, in the future can be considered as a potential object for the placement of an SGP power plant operating on the principle of mixing sea water and hypersaline solution.

4. *Sivash* is a vast shallow bay of the Azov Sea, with a rugged coastline, many peninsulas, capes, bays. Sivash is connected to the Azov Sea by the shallow and narrow Genichesk Strait, located at the northern end of the Arabat Spit. The Chongar Peninsula divides the Sivash into two parts: western and eastern. The total area of Sivash is about 2530-2540 km^2 (1430 km^2 – the eastern part, 1100 km^2 – the western part, which is the largest of the considered reservoirs). Under natural conditions, the area of the eastern part of Sivash changes little during the year, while the western part, depending on meteorological and hydrological conditions, sharply doubles in winter and is largely dried up in summer, turning into extensive salt droughts.

Currently, two artificial dams, with the help of which the hydrochemical regime and the supply of brine are regulated, divide the Sivash into three separate parts: Eastern, Central and Western Sivash (Fig. 3.5).

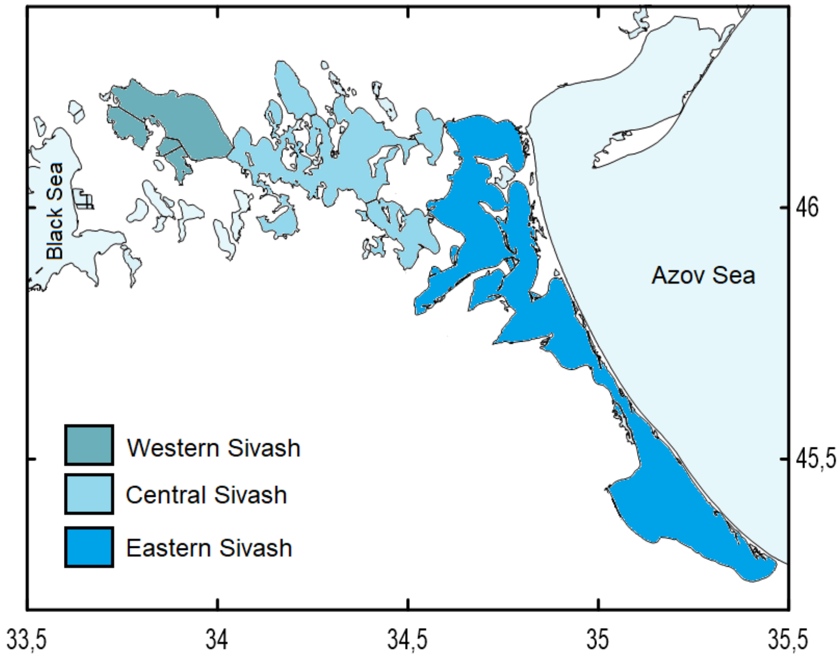

Fig. 3.5 Map of Sivash

In general, Sivash is very shallow, it is characterized by depths < 0.5 m (32 % of its area), and less than half (46 % of its area) falls at depths of 1.0-2.5 m. Before the construction of the dams, the brine concentration in the western part of the Sivash experienced significant changes (from 50.0 to 260.0 ‰). After the construction of the dams, the western part was turned into an isolated basin with controlled hydrological and hydrochemical regimes, and the selected Middle reservoir was turned into a huge evaporation basin for the preparation of high-concentration brines. The brine of the Western Sivash enters through the brine pipeline to the Aigul Lake, which has been turned into an intermediate brine storage, and then to the Old Lake, from where the brines are fed to the plant for processing (plants were built on the basis of Sivash: Perekop Bromine Plant, Crimean Titanium Dioxide Plant for the manufacture of phosphate fertilizers and Crimean soda plant were built [134]. The Western Sivash is used to obtain concentrated brine for the production of magnesia products, gypsum and bromine, as well as a large amount of sodium chloride. The value of overland flow, reaching 7.2 million m^3 in a dry year, 24.3 million m^3 on average, and 60.5 million m^3 in a rainy year, is commensurate with the evaporation of brines in the Western Sivash, which is equal to 25.6 million m^3 per year under steady hydrological and hydrochemical regimes.

The salinity of the brine in different parts of the Sivash is not the same and changes over time and depends on the totality of the life conditions of the reservoir – currents, meteorological and hydrological factors. The waters of the Azov Sea with a salinity of 11.0-12.0 ‰ enter to the Eastern Sivash [135]. When the waters move to the west, the concentration of brine occurs and at Cape Kugaran it already reaches 230.0-260.0 ‰. On average, salinity in the eastern part of the Sivash ranges from 115.0-135.0 ‰. In the western part, after the construction of dams, salinity is maintained at the level of 240.0-260.0 ‰. The brines of the Eastern Sivash are distinguished by the greatest constancy of salinity, where seasonal fluctuations do not exceed 15.0-20.0 ‰. The period of maximum brine concentrations lasts from June to October-November, when evaporation is approximately three times higher than overland flow and precipitation. In the Western Sivash, before regulation, sharp fluctuations in salinity were typical. As a result of surge currents and overland flow, the concentration of brine decreased over several days from 260.0-270.0 ‰ to 50.0-70.0 ‰.

Thus, the Western Sivash with its large reserves of highly concentrated brine is a good source of hypersaline solution for the SGP power plant. The source of water with low salinity in this case can be the waters of the Karkinitsky Bay of the Black Sea (salinity 15.0-18.0 ‰), remote from the western tip of the Western Sivash at a distance of 9.5 km near Armiansk. Moreover, today there is a channel connecting the Karkinitsky Bay and the Western Sivash, which reduces the cost of building infrastructure associated with the SGP power plant.

The results of calculating the maximum net power for the above objects are shown in Table 3.5, where c_D – average concentration of brine in limans, c_F – salinity in the area of the proposed water intake in the Black Sea (the Danube River in the case of the Alibey and Shagany limans).

Table 3.5 The maximum net power W_{net}^{max} (MW) per 1 m^3 of solution passing through the membrane

Object name	**Area, km^2**	**Summer**			**Winter**		
		c_D, ‰	**c_F, ‰**	**W_{net}^{max}, MW/m^3**	**c_D, ‰**	**c_F, ‰**	**W_{net}^{max}, MW/m^3**
Alibey	98	48-54	0	1.91-2.15	25	0	0.9
Shagany	71	45-53	0	1.79-2.11	25	0	0.9
Kuialnyk	25-60	320	14	12.2	200	14	6.67
Sasyk-Sivash	75,3	272	18	10.29	184	18	5.96
Western Sivash	1100	260	18	9.65	240	15	8.07

As can be seen from Table 3.5 highest values W_{net}^{max} obtained in the summer months, when the salinity in limans reaches its maximum and, consequently, its difference with the salinity of sea (river) water increases. Proceeding from W_{net}^{max}, obtained for the Western Sivash, where the salinity is maintained artificially at certain values, it can be seen that the annual amplitude has a smaller value, which provides more stable conditions.

CONCLUSION

The Black Sea region countries have high potential for the blue economy, which is not fully realized. The Black Sea's wealth of living marine resources makes it possible to satisfy the region's residents' needs for fish and seafood, as well as export raw materials and processed products to other countries. For the successful development of the fishing industry, it is necessary to expand the market for the sale of products, increase and update the fishing fleet and related port infrastructure, monitor the environmental condition of fishing areas, laws regulating production (strict control over overfishing and protection from poachers), and provide state assistance to small and medium-sized businesses.

The mariculture sector is innovative and has been developing rapidly in recent years in the region, but legislative regulation and government support for enterprises are required.

Tourism is one of the leading sectors of the blue economy in the Black Sea region. The main challenge to the tourism sector in the last decade was the COVID-19 pandemic and the subsequent lockdowns, which negatively affected the indicators in the tourism sector of all Black Sea countries.

Port activities are one of the long-established sectors of the blue economy and bring significant revenues to the budgets of the Black Sea countries. It should be noted that COVID-19 has also had a negative impact on the port services sector due to the reduction in cargo flow due to border closures, which has led to a decrease in cargo handling at the Black Sea seaports. The complex geopolitical situation in the Black Sea, the closure of navigation as a result of military actions negatively affected port activities in Ukraine and led to the redistribution of cargo flow among neighboring countries.

The main problem of the Black Sea countries' merchant fleet is the outdated material and technical base of the fleet, old ships. It is necessary to update and increase the size of the merchant fleet in all Black Sea countries. Imports of maritime freight transport and related services exceed exports in all Black Sea countries, meaning that countries spend money on freight transport every year rather than earning money from it. Shipbuilding in the Black Sea region makes a small contribution to the share of global shipbuilding. It is necessary to increase volumes, update the base of ship repair plants, switch to modern technologies and train our own qualified engineering and working personnel.

Due to unique physical-geographical, hydrological and climatic conditions, Black Sea region is the habitat of many valuable species of plants and animals, as well as provide a significant amount of ecosystem services (water and food, regulation of floods, droughts, land degradation, soil formation, nutrient cycling, photosynthesis, biodiversity, cultural, recreational and spiritual).

The region's wealth of natural resources provides opportunities for the successful development of the marine renewable energy industry in the Black and Azov Seas. The total area of water suitable for the development of offshore wind energy is about 98500 km^2. On the north-western shelf of the Black Sea, as well as throughout the entire water area of the Azov Sea, there are significant areas with depths of less than 50 m and a distance from the coast of not more than 200 km, suitable for placing both floating and fixed OWT. Significant water areas with high wind power classes in the northwestern and northeastern parts of the Black Sea, as well as the Azov Sea, allow the installation of offshore wind farms capable of generating energy on an industrial scale. Installation and connection of the OWT to the hybrid energy complex can partially compensate for the uneven supply of energy resources and improve the reliability of energy supply to consumers coastal regions of Bulgaria, Georgia and Turkey.

The Black Sea region is promising for the development of innovative sectors of the blue economy. There are objects in the northwestern Black Sea region, in the waters of which, as soon as technologies become available, it will be possible to implement SGP projects. The Kuialnyk Liman, Sasyk- Sivash lake and Western Sivash have the most favorable conditions, where the highest power indicators are shown when using the sea water – hypersaline solution scheme, in which freshwater is not consumed. Taking into account the shortage of freshwater resources and, based on the trend of climate change in the northwestern Black Sea region towards the development of arid conditions, the need for their conservation in this region will continue to increase. At the same time, these same changes already today lead to a change in the hydrological regime of the estuaries of the northwestern Black Sea region, as a result of which the water content is reduced and mineralization (salinity) increases. If the technical problems associated with the implementation of SGP projects are successfully resolved, this would provide the population with additional energy, and also help to preserve the natural state of the estuaries that are in the process of degradation.

Overall, the Black Sea region is characterized by a combination of abundant marine and coastal natural resources, a favorable location at the crossroads of trade routes leading from Asia to Europe, and high human capital, providing opportunities for the development of a blue economy. At the same time, the challenging geopolitical situation that has developed in the region in recent years imposes restrictions on the implementation and development of maritime activities.

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ANNEXES

ANNEX A

Table A.1

Capture production of marine living resources (thousand tons of live weight)

Countries	Years												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bulgaria	9.7	8.1	8.1	9.5	8.5	8.7	8.5	8.5	8.5	10.3	6.2	8.9	5.5
Georgia	40.5	26.5	12.0	15.5	19.0	22.5	26.7	99.6	90.1	89.9	83.2	75.3	68.5
Romania	0.2	0.5	0.8	1.6	2.2	4.8	6.8	9.6	7.7	7.1	4.5	3.1	6.2
Türkiye	332.5	365.5	252.8	235.9	171.3	317.4	186.7	230.3	147.6	346.2	228.4	226.9	193.4
Ukraine	41.1	44.8	41.5	44.7	4.6	5.8	7.1	5.4	9.1	14.1	9.8	8.3	0.2

Table A.2

Aquaculture production in marine waters (thousand tons of live weight)

Countries	Years												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bulgaria	0.70	0.64	0.88	1.83	2.52	3.37	3.93	3.39	2.53	2.93	2.15	2.59	1.44
Georgia	n/a	n/a	n/a	n/a	0.02	0.02	0.06	0.08	0.10	n/a	n/a	n/a	n/a
Romania	n/a	0.001	0.009	0.016	0.037	0.055	0.045	n/a	n/a	n/a	n/a	n/a	n/a
Türkiye	89.15	88.44	101.25	100.85	126.89	138.88	151.79	172.49	209.37	256.93	293.18	335.64	368.74
Ukraine	0.08	0.06	0.12	0.07	0.07	0.07	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table A.3

Value of aquaculture produced in marine waters (US$ million)

Countries	Years												
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Bulgaria	0.799	0.867	0.842	2.157	2.940	3.326	3.247	2.864	2.307	2.932	2.055	2.842	2.009
Georgia	n/a	n/a	n/a	n/a	0.091	0.075	0.215	0.274	0.351	n/a	n/a	n/a	n/a
Romania	n/a	0.002	0.014	0.031	0.152	0.181	0.162	n/a	n/a	n/a	n/a	n/a	n/a
Türkiye	482.94	479.14	590.64	600.83	695.85	689.12	815.90	866.91	906.87	1038.07	1225.13	1715.06	2062.39
Ukraine	0.095	0.076	0.140	0.084	0.084	0.084	n/a	n/a	n/a	n/a	n/a	n/a	n/a

ANNEX B

Table B.1

Imports of marine and coastal tourism services (US$ million at current prices)

Countries	Years												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bulgaria	229	249	247	285	302	277	326	395	442	434	245	317	n/a
Georgia	15	14	15	11	9	13	9	16	33	31	9	11	n/a
Romania	n/a	n/a	n/a	379	654	646	760	1545	1933	2173	1015	1932	n/a
Türkiye	2728	2476	1914	2824	2749	2941	3461	3389	3064	2842	702	1094	2813

Table B.2

Exports of marine and coastal tourism services (US$ million at current prices)

Countries	Years												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bulgaria	1228	1337	1268	1381	1399	1104	1295	1434	1592	1503	550	834	n/a
Georgia	169	281	427	542	568	565	715	949	1143	1180	189	466	n/a
Romania	n/a	n/a	n/a	262	330	150	175	606	700	786	316	806	n/a
Türkiye	18581	20534	21190	23349	24794	22192	15269	18704	21241	27883	9824	20802	33344

ANNEX C

Table C.1

Imports of port services, and also related infrastructure services and logistical services (US$ million at current prices)

Countries	Years												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bulgaria	23.6	22.4	45.1	34.1	30.8	45.7	29.0	25.2	35.3	22.1	24.7	8.4	56.7
Georgia	5.0	3.4	2.6	2.5	2.1	1.7	1.6	1.2	0.5	0.8	0.4	0.4	0.8
Romania	n/a	n/a	n/a	28.8	38.2	39.4	29.5	25.9	30.7	137.1	75.1	109.9	n/a
Türkiye	n/a	n/a	35.0	46.0	48.0	108.0	102.0	590.0	450.0	86.0	106.0	602.0	n/a
Ukraine	115.0	134.0	99.0	218.0	110.0	61.0	67.0	95.0	100.0	135.0	134.0	231.0	205.0

Table C.2

Exports of port services, and also related infrastructure services and logistical services (US$ million at current prices)

Countries	Years												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bulgaria	4.8	4.5	6.0	8.5	22.4	28.6	30.5	98.3	61.4	70.5	60.9	37.5	40.5
Georgia	101.9	133.6	125.9	153.5	147.8	163.0	153.3	129.1	123.5	110.3	98.1	83.4	119.2
Romania	n/a	n/a	n/a	96.1	98.2	98.9	88.2	73.7	68.2	161.7	130.8	171.6	n/a
Türkiye	154.0	226.0	236.0	1717.0	1804.0	1554.0	1910.0	1784.0	2030.0	1870.0	2106.0	2779.0	3551.0
Ukraine	1180.0	1158.0	1198.0	1065.0	818.0	721.0	631.0	568.0	488.0	559.0	570.0	573.0	357.0

Table C.3

Container handling at ports (TEU thousand)

Countries	Years												
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Bulgaria	142.6	147.6	169.9	180.4	195.5	201.1	206.1	228.5	241.7	261.9	254.6	245.2	254.9
Georgia	242.4	284.4	356.7	403.4	447.0	276.8	251.0	n/a	348.2	601.5	490.7	401.3	n/a
Romania	556.7	648.5	684.1	661.1	668.0	689.0	711.3	696.4	668.0	666.0	643.0	632.0	772.0
Türkiye	n/a	n/a	59.0	55.3	67.3	73.7	6.6	77.3	79.3	73.2	0.1	112.5	118.7
Ukraine	690.3	799.1	720.3	787.9	670.3	480.8	680.6	723.6	845.2	1007.3	1048.7	1022.4	n/a

ANNEX D

Table D.1

Imports of maritime transport (freight) and related services (US$ million at current prices)

Countries	Years												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bulgaria	444.1	575.1	665.1	642.4	983.2	460.6	650.3	1073.0	578.5	606.0	431.4	702.0	989.2
Georgia	149.3	229.6	236.3	292.3	306.3	303.1	255.2	270.4	308.7	320.0	273.5	343.7	484.0
Romania	n/a	n/a	n/a	197.72	222.77	213.19	197.57	234.95	223.04	232.45	215.81	493.40	n/a
Türkiye	4995.0	4985.0	5294.0	4334.0	4392.0	3502.0	3409.0	3422.0	4487.0	5097.0	5000.0	7269.0	10081.0
Ukraine	850.0	537.0	696.0	579.0	442.0	340.0	348.0	347.0	477.0	690.0	704.0	1128.0	1028.0

Table D.2

Exports of maritime transport (freight) and related services (US$ million at current prices)

Countries	Years												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bulgaria	33.2	28.9	24.9	50.3	59.0	42.3	57.9	46.7	48.3	35.8	62.0	78.3	73.0
Georgia	8.3	4.9	4.1	5.9	5.3	4.8	5.2	4.5	2.3	9.9	8.8	23.3	78.5
Romania	n/a	n/a	n/a	96.1	98.2	98.9	88.2	73.7	68.2	161.7	130.8	171.6	n/a
Türkiye	1212.0	1193.0	1429.0	2372.0	2491.0	2148.0	2352.0	2711.0	2414.0	2083.0	1788.0	2683.0	2524.0
Ukraine	48.0	50.0	38.0	54.0	34.0	14.0	32.0	43.0	28.0	37.0	35.0	43.0	10.0

ANNEX E

TableE.1

Imports of ocean-related services (US$ million at current prices)

Countries	Years												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bulgaria	697	846	957	961	1316	783	1005	1493	1056	1062	701	1027	1531
Georgia	170	248	255	306	317	319	266	288	343	353	283	355	595
Romania	n/a	n/a	n/a	607	917	901	988	1808	2188	2542	1307	2536	n/a
Türkiye	n/a	n/a	n/a	7193	7187	6491	6978	6913	8141	8389	5789	8469	13496
Ukraine	1855	1759	2004	2141	1738	1489	1564	1705	1877	2236	1003	1625	1687

Table E.2

Exports of ocean-related services (US$ million at current prices)

Countries	Years												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bulgaria	1267	1372	1300	1442	1482	1176	1384	1580	1703	1611	674	951	607
Georgia	281	421	558	703	722	734	874	1083	1270	1301	297	573	1121
Romania	n/a	n/a	n/a	528	666	412	379	806	882	1080	560	1161	n/a
Türkiye	19947	21953	22855	27450	29101	25906	19542	23222	25693	31843	13722	26266	39422
Ukraine	2271	2345	2509	2483	1279	1020	942	946	900	1021	651	764	620

ANNEX F

Table F.1

Indicators of maritime transport in Ukraine

Indicator	unit	Years					
		2016	2017	2018	2019	2020	2021
Gross weight of goods handled морской транспорт	million tons	3	2.3	1.9	2.1	1.8	1.9
Freight shipped, by sea	1000 tons	3033	2253	1892	2120	1812	1852
By type of communication routes: international	1000 tons	1903	1408	1207	1089	969	1133
By type of communication routes: coastal	1000 tons	1130	845	685	1031	843	719
Freight traffic sea transport by type of traffic	mln.tkm	2538.7	2848.6	1822.8	1773.9	1504.4	1591.1
international	mln.tkm	2216	2375.2	1576.9	1380.8	1158.5	1415.3
coastal	mln.tkm	322.7	473.4	245.9	393.1	345.9	175.8
Freight transportation on average per day	1000 tons	8	6	5	6	5	5
Average distance of transportation of one ton of cargoes by maritime transport	km	837	1264	963	837	830	859
Average distance of transportation of one ton of cargoes by maritime transport in international traffic	km	1165	1687	1306	1267	1195	1249

Наукове видання

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Монографія

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