Supplementary File S3

1. Origin and ecological importance

Table 1.1. Advances in Mexico in the strategic line of origin and ecological importance. Number of projects or initiatives are traceable via an ID number from Supplementary File 1. The institutions that have conducted these studies are listed.

Subarea	Number of projects/initiatives and ID	Institutions/ organizations
Origin of the phenomenon	N=1 1740	CICESE
Changes in biological and genetic structure of floating biomass (morphotypes)	N=7 1120; 1150; 1160; 1200; 1250; 1260; 1840	Instituto de Ciencias del Mar y Limnología (ICML, UNAM); Universidad Autónoma Metropolitana (UAM); Centro de Investigaciones Biológicas del Noroeste S.C (CIBNOR); CINVESTAV
Carbon sink and sediment supply to the deep sea and coasts	N=4 1090; 1240; 1270; 1400	CICY; Centro de Investigación en Materiales Avanzados S.C. (CIMAV); ICML, UNAM; CIIEMAD, IPN
Biological associations	N=3 1210; 1220; 1230	CIBNOR; ICML, UNAM; CICY

1.1.Origin of the phenomenon

A recent investigation involving researchers from CICESE, revealed that there is no evidence that nutrient flows from rivers, including the Amazon, have increased in the last 15 years. Therefore, they concluded that the association with increased *Sargassum* blooms is unlikely [31].

1.2.Changes in biological and genetic structure of floating biomass (morphotypes)

A group of researchers from ICML estimated the biomass and composition of *Sargassum* that reached the Mexican Caribbean coast from September 2016 to May 2020. This study determined that the species composition and morphotypes of *Sargassum* in Mexico differ from those commonly reported in the Sargasso Sea. In these *Sargassum* strandings, the following species were identified: *S. natans I* (to a lesser extent), *S. natans VIII* and *S.*

fluitans III, the latter being the predominant form throughout the study period (>60% of the total biomass) [32].

Researchers from CINVESTAV used two approaches for the identification of *Sargassum* species, one by traditional taxonomy and the other by chemical characterization. For the latter, cell wall polysaccharides were extracted and characterized and specific compounds were searched for in the different species. The chemical analysis method proved to be a useful auxiliary tool to complement taxonomic identification [113]. Another study characterized *Sargassum* in terms of its abundance, species composition and chemical content using a combination of *in situ* sampling and remote sensing assessments. Significant spatial variation in biomass abundance and species composition was found and was related to local environmental conditions. The biochemical composition of the *Sargassum* had spatial variation in carbon content, heavy metals (particularly Fe and As) and isotopic composition [26].

1.3.Nutrients supply to deep sea ecosystems

A study from CIMAV analyzed the role of *Sargassum* in CO_2 absorption through binding as calcite. This study determined that approximately 5% of the CO_2 captured by *Sargassum* is converted to calcium carbonate in its calcite phase. By extrapolation, it can be determined that the Atlantic *Sargassum* Belt retained approximately 19 million tons of CO_2 between 2011 and 2019 [33]. Researchers from ICML also investigated the role of *Sargassum* in CO_2 fixation from the calcareous epiphytic communities that colonize it (e.g., bryozoans, serpulid worms and red algae). This study determined that *Sargassum* plays a key role in contributing calcium carbonate to the coasts of the Mexican Caribbean, with 179 kg of $CaCO_3$ per meter of coastline [34].

1.4.Biological associations

Two studies focused on these biological associations were identified: The CIBNOR investigated the occurrence and the percentage of coverage of hydroids in *Sargassum* collected on the beach of Puerto Morelos, Quintana Roo, finding a total of 14 taxa of hydroids associated with the macroalgae [35]. Scientists from ICML sampled the motile macrofauna associated with *Sargassum* on the reef lagoon. This study found 32 *taxa* and 8 *phyla* associations. The main phyla were Arthropoda (48%), Annelida (41%) and Mollusca (15%) and the most abundant species (accounting for 89% of the individuals) were species typically associated with *Sargassum* [36].

2. Monitoring, modeling and early warning

Table 1.2. Advances in Mexico within the strategic line of monitoring, modeling and early

warning

Subarea	Number of projects/initiatives and ID	Institutions/ organizations
Remote sensing and ocean and coastal monitoring	N=9 120; 130; 150; 170; 1500; 1720; 1750; 1760; 1900	CONABIO; ECOSUR; Laboratorio de Ecología Espacial y del Movimiento (LEEM, UNACAR); Laboratorio Nacional de Observación de la Tierra (LANOT, UNAM)
Numerical models for drift prediction	N=10 120; 160; 1720; 1750; 1760; 1820; 1850; 1860; 1880; 1900	Centro de Ciencias de la Atmósfera (CCA, UNAM); Unidad Académica Sisal (SISAL, UNAM); IMTA; CICESE Observatorio Oceanográfico Regional Costero (OORCo) of the Universidad Autónoma de Baja California (UABC); CCA; LEEM, UNACAR
Early Warning	N=6 100; 110; 120; 1480; 1750; 1760	CONABIO; Red de Monitoreo del Sargazo Cancún; Observatorio Ciudadano del Sargazo; SEMA
Monitoring *in situ*	N=6 140; 1730; 1760; 1780; 1860; 2030	SEMARNAT; INECC; SEMAR; INAPESCA; ECOSUR

2.1.Remote sensing and ocean and coastal monitoring

In the government sector, CONABIO has developed SIMAR, an interactive platform that includes *in situ* data, climate models, satellite products and other geospatial information (https://simar.conabio.gob.mx/). It is equipped with the Early Warning System of *Sargassum* (SATsum), which allows the visualization of the floating *Sargassum* with a daily resolution of 1 km, using images from the satellite Aqua-MODIS. The SEMAR uses satellite products of the University of South Florida (USF) and a detection algorithm they developed to monitor *Sargassum* at open sea [114].

In academia, ECOSUR has developed a neural network called ERISNet for the detection of *Sargassum* in the coastal zone, whose algorithm has 90% of successful recognition of *Sargassum* in images from the satellite Aqua-MODIS [43].

A group of researchers from UNACAR, have used high spatial-resolution satellite images (from satellites Landsat 8 and Sentinel 2) and a multi-index analysis of *Sargassum* pixel detection with more than 80% successful recognition rate [44]. The high spatial resolution (<20 m) is limited by low temporal resolution of approximately 15 days. The products of this research have been used primarily to generate historical time series at fine spatial scales [115].

The LANOT is a consortium of education and research institutions, including the federal government and private sectors, located at the Instituto de Geografía (IG), UNAM (http://www.lanot.unam.mx/). The LANOT monitors *Sargassum* rafts by satellite imagery of Sentinel-2, GOES-16, GEONET Cast and conduct historical reconstructions of influxes to create a prediction system [45].

2.2.Numerical models for drift prediction

In academia, CICESE, in collaboration with the Institut De Recherche Pour Le Developpement in France, conducts a project called FORESEA to understand the origin and dynamics of *Sargassum* in the open ocean and coastal system. Within the framework of this project, a drift model named NEMO Sarg 1.0 was developed. It integrates current and wave transport, characteristics of *Sargassum* biology and physiology and nutrients that define its growth. This model intends to predict the seasonal cycle and the large-scale distribution of *Sargassum* biomass [39,48].

The OORCo, in collaboration with ECOSUR and UNACAR, will soon place high-frequency radars on the Mexican Caribbean coast that will determine current patterns at very fine spatial and temporal resolutions. Information provided by this radar network will be used to improve current resolution and predictive capability of coastal models based on the understanding of coherent Lagrangian structures [49].

The CCA, UNAM, studies the dynamics of pelagic *Sargassum* transport in the Mexican Caribbean by means of numerical modeling and *in situ* observations. Preliminary results of this research indicated that the thickness of the *Sargassum* rafts affects the direction and speed of drift. Therefore, wind drag is pivotal to determine place and timing of *Sargassum* influxes [47].

SISAL Academic Unit, UNAM, seeks to establish an early warning system for *Sargassum* influxes based on new statistical methodologies and the use of Lagrangian simulations. Preliminary results show that coherent Lagrangian structures form natural barriers that determine the number of particles that can reach the coast and beaches. The impact of the wind is a determining factor for a significant accumulation of *Sargassum* on the coast [46].

The IMTA has presented a diagnosis of the seasonal, annual and interannual variability of atmospheric circulation in the Atlantic Ocean and the Caribbean, identifying the atmospheric conditions under which *Sargassum* arrives in the coasts of Quintana Roo. The results recognized that atmospheric conditions for transport of *Sargassum* to the coast of Quintana Roo are more favorable in summer with stronger winds [116].

2.3.Early Warning

In addition to the SIMAR platform of CONABIO, there are other initiatives from civil society and the government sectors for the development of a "*Sargassum* traffic light" at a municipal level. The Red de Monitoreo del Sargazo Cancún is an online tool to inform and alert the public about the massive influxes of *Sargassum* to the beaches of Quintana Roo (https://www.facebook.com/RedSargazo/?ref=page_internal). This site, with a total of 149 909 followers (10/2021), is the most consulted platform of its kind by the general public. Given the high number of visits to this site, especially by tourists, this type of social initiative could have a significant impact on tourist travels within certain regions. Another similar initiative is the Observatorio Ciudadano del Sargazo (https://www.viajefest.com/sargazo-en-quintana-roo/), a web page with information for tourists that produces weekly reports of the presence of *Sargassum* on the main beaches. It is updated with the participation of residents, visitors and tourists, as well as businesses and locals who share photos on a daily basis.

SEMAR, in collaboration with SEMA of Quintana Roo, publishes a "traffic light" associated with the presence and abundance of *Sargassum* in 47 beaches in the region (https://qroo.gob.mx/sema/comunicado-de-presencia-de-sargazo-en-playas-en-el-estado-de-quintana-roo/). This tool collects information gathered by municipalities, as well as satellite data obtained from the Optical Oceanography Laboratory of USF.

2.4. Monitoring *in situ*

The Sistema de Monitoreo de Sargazo Recolectado (SIMSAR), developed by SEMARNAT, INECC and SEMAR (https://app.semarnat.gob.mx/sargazodesa/), aims to systematize information on the volumes of *Sargassum* that arrive and are collected on land and sea. This data will be used for research and decision-making purposes.

The INAPESCA in Quintana Roo conducts research on population dynamics of *Sargassum* (e.g., growth and sink rates, available biomass, spatial patterns, etc.) using time series analyses, data *in situ* from various sources and monthly *Sargassum* biomass data estimated and reported by the USF [50]. The purpose of this research is to have a tool that

predicts *Sargassum* influxes on seasonal and interannual bases and to identify patterns that helps to understand the dynamics and behavior of the macroalgae.

ECOSUR has developed a system "Collective View" that incorporates citizen science to describe the temporal and spatial variation of *Sargassum* on beaches of Quintana Roo. [52]. Collective view consists of an innovative approach for monitoring and detecting *Sargassum* on beaches using a mobile application for collecting geo-referenced images that, through a deep learning system for automatic classification, makes it possible to obtain estimates of the quantities of *Sargassum* that arrive to the coast [51,52].

3. Socioeconomic and environmental impacts

Table 1.3. Advances in Mexico in the strategic line of socioeconomic and environmental impacts.

Subarea	Number of projects/initiatives and ID	Institutions/ organizations
Tourism	N=8 870; 980; 1020; 1070; 1320; 1560; 1570; 1700	Banking groups BBVA, BANORTE, Grupo Monex; Asociación de Hoteles de Cancún y Puerto Morelos; Asociación de Hoteles de la Riviera Maya; Universitat Rovira i Virgili; CINVESTAV
Commercial fisheries	N=1 920	ECOSUR
Human health and air pollution	N=2 1680; 620	CCA, CICY
Leachates, eutrophication and contamination of aquifers and cenotes	N=5 890; 900; 910; 1060; 620	ICML; CONAGUA; IMTA; CICY
Species of the reef lagoon and coastal zone	N=15 850; 860; 880; 940; 950; 960; 970; 990; 1000; 1010; 1030; 1040; 1050; 1080; 1100	ICML; Comité Estatal de Tortugas Marinas de Quintana Roo; CIBNOR; Universidad Autónoma de Querétaro (UAQ); ECOSUR
Erosion of beaches	N=0	NA

3.1.Tourism

Three banking groups (BBVA, BANORTE and Grupo Monex) have annually reviewed several of these indicators and have developed reports and guidelines (Supplementary File 1). The Cancun, Puerto Morelos and Riviera Maya Hotels Association have also analyzed hotel occupancy as an indicator of the possible impacts. The private sector's analyses do not show conclusive results regarding the impact of *Sargassum* on tourism, since not all indicators have shown a drop in relation to peak atypical influxes. Although drops of 2% to 6% are reported in hotel occupancy in 2019 compared with 2018, these drops cannot be distinguished from other variables such as the increase of houses for rent through platforms such as Airbnb, the lack of tourism promotion, or the increase in crime rates [53].

3.2.Commercial fisheries

Except for a master's thesis of 2010 of ECOSUR, which confirms this type of impact on the fishery for the spotted ray Aetobatus narinari [60], no other projects or initiatives on this topic were identified.

3.3.Human health and air pollution

In addition to some ongoing projects (Supplementary File 1), the IMTA sampled water and degraded *Sargassum* on the beaches of the region to measure the amount of enterobacteria. Pseudomonas aeruginosa, a bacterium which can cause infections in humans, was found in one sample. *Shewanella putrefaciens*, a bacterium that may rarely cause septic shock [117], was found in most of the samples [60]. Hydrogen sulfide was also present in high (i.e., toxic) concentrations in one of the samples [60].

3.4.Leachates, eutrophication and contamination of aquifers and cenotes

A group from the CICY determined that a greater promotion of cenotes tourism occurred during massive influxes, so tourists choose to visit cenotes instead of beaches to avoid *Sargassum*. This peak in cenote tourism is related to an increase of contaminants in these ecosystems [14].

3.5.Species of the reef lagoon and coastal zone

The Comité Estatal de Tortugas Marinas de Quintana Roo has conducted several observations of *Sargassum* and its possible effects on turtles in their different developmental stages (Supplementary File 1). In academia, two theses were identified

from the CIBNOR and the UAQ. The first thesis shows that greater oxidative damage in turtles is related to sites with greater tourism and greater *Sargassum* influxes [62]. The second revealed that in 2018, 40% fewer turtle hatchlings were recorded compared to the previous year. The most frequent mentioned factors as possible direct impacts of *Sargassum* on sea turtles are a) Stranded *Sargassum* obstructs the passage of hatchlings to the sea, b) heavy machinery for cleaning *Sargassum* influences the turtles' ability to nest, c) *Sargassum* at-sea barriers obstruct the path of hatchlings to the open sea, d) stranded *Sargassum* affects nest location and number [63].

ICML had three relevant investigations. The first one found that eutrophication, caused by *Sargassum*, is a major factor in reef deterioration in the region [64]. The second described a mass mortality event of fauna associated with the *Sargassum* influx event in 2018. Among the affected species were neritic fish, demersal fish and crustaceans [13]. The third study determined that massive *Sargassum* influxes caused nearshore seagrass ecosystems to be replaced by a community dominated by calcareous rhizophytic algae, drift algae and epiphytes, which in turn resulted in a loss of 61.6% to 99.5% of the seafloor. Total or partial mortality of coral reefs was also recorded during the 2015 influx event [12].

In ECOSUR, three research projects were conducted. The first one documented that, in a laboratory environment, there was a direct relationship between *Sargassum* leachates and changes in the swimming behavior of coral larvae. It was concluded that leachates may reduce larval dispersal and genetic diversity and therefore represent a threat to the reproduction of different coral species. The second research evaluated the impact of influxes on the trophic dynamics of sea urchins *Diadema antillarum*, a key herbivore in Mexican Caribbean reef systems [65]. Leachates reduced the taxonomic diversity of macroalgae that are a primary food source for these urchins [65]. The third research evaluated the effect of *Sargassum* influxes during 2018 on the structure and composition of morphofunctional algal groups and coral health, finding a decrease in the living coral tissue with respect to that recorded in 2017, as well as variations in the structure and algal composition of the study site [66].

3.6.Erosion of beaches

The environmental impacts of different *Sargassum* collection technologies on beaches have not been documented in Mexico.

4. Containment, harvest and disposal

Table 1.4. Advances in Mexico within the strategic line of containment, harvest and disposal.

Subarea	Number of projects/initiatives and ID	Institutions/ organizations
Containment and deflection at sea	N=9 610; 640; 650; 660; 680; 710; 720; 740; 1800	Companies GOIMAR, Dakatso, Ocean Solutions México, Manufacturas Industriales DP, Sargazo Solutions, DESMI, The Ocean Cleaner; SEMARNAT
Harvest at sea	N=10 610; 650; 660; 680; 700; 710; 720; 740; 750; 1800	All aforementioned companies, Preyco, Tecno Productos GAB
Collection at beach	N=6 610; 630; 650; 690; 720; 1830	IPN; local government
Temporary transfer and final disposal stations	N=4 610; 650; 680;1800	Grupo Dakatso

4.1.Containment and deflection at sea

In Mexico, several companies that have developed *Sargassum* barriers (see table above).

4.2.Harvesting at sea

SEMAR has developed *Sargassum* trawlers that have a processing capacity of ~20 tons per day (SEMAR, 2021). The companies in Mexico that collect *Sargassum* at sea can be consulted in the above table.

4.3.Collecting at beach

In academia, there have been some efforts to develop collection-at-beach technologies. For example, a group of students at IPN developed a prototype of a sustainable electronic vehicle that would prevent soil erosion. This technological innovation would also have the capacity to clean 60 kilometers of beach and collect up to four tons of macroalgae in three hours (Supplementary File 1).

When *Sargassum* strandings are intense, members of the civil society, students and municipal and state employees of Quintana Roo conduct "clean-up days" [118]. In 2019, a strategy was implemented in the Cancun area so that people arrested by the municipal police for administrative offenses (including driving under the influence) could pay their

fine by collecting *Sargassum* on the beach [120]. Other types of civil society initiatives are conducted by beach clubs and restaurateurs. For example, in 2021 the "Sargazoton" was held in Cozumel, where the manual collection of *Sargassum* on the beaches was encouraged by exchanging *Sargassum*-full sacks for food and drink provided by the owners of these establishments.

4.4.Temporary transfer and final disposal stations

The specifications and location of *Sargassum* treatment sites are defined by the federal entity [69], in concurrence with authorities of the three levels of government. However, there are still large gaps in information about compliance of these specifications and, in general, about the *Sargassum* transport chain. During this study, we did not find information accessible to the general public for the location and/or characteristics of *Sargassum* transfer and disposal sites.

5. Potential uses

Table 1.5. Advances in Mexico in the line of potential uses of *Sargassum*.

Subarea	Number of projects/initiatives and ID	Institutions/ organizations
Agriculture industry and livestock goods	N= 16 220; 250; 280; 300; 360; 390; 400; 410; 480; 490; 520; 790; 1180; 1810; 1960; 2040	Moon Palace Hotels; Universidad de Guadalajara (UdG); Centro de Investigación en Biotecnología Aplicada (CIBA, IPN); Instituto Tecnológico de Conkal (ITConkal); Instituto Tecnológico de Chetumal (ITCH); Colegio de Postgraduados Campus Puebla (CP); CICY; Universidad Popular Autónoma del Estado de Puebla (UPAEP); Companies Alquimar, Dianco, Salgax, Grupo Dakatso, C-combinator; UPQROO; ITM

Chemistry, pharmaceutics and nutritional supplements	N=14 210; 220; 230; 350; 430; 510; 620; 1420; 1510;1550; 1580; 1590; 1710; 1980	Companies Metco, Creamos Más, Alquimar; Tecnológico de Monterrey; UQROO; CICY; CINVESTAV; Universidad La Salle
Ecomaterials	N=14 190; 240; 300; 310; 370; 400; 440; 450; 500; 520; 730; 760; 780; 1940	Companies BlueGreen, Grupo Daktso, Renovare, Abaplas, Energryn, Dianco, Sargánico; Universidad Intercultural Indígena de Michoacán (UIIM); CICY; Universidad Abierta y a Distancia de México (UNADM)
Livestock feed	N=1 260	Centro Interdisciplinario de Ciencias Marinas (CICIMAR, IPN)
Bioenergetics	N=13 180; 200; 270; 420; 570; 770; 1190; 1410; 1610; 1660; 1670; 1910; 2020	(UdG), Escuela Nacional de Ciencias Biológicas (ENCB, IPN); Universidad Autónoma de Coahuila (UAdeC) Companies Grupo Transportación Marítima Mexicana, Nopalimex, G2E; Universidad La Salle; CICY; Centro Interdisciplinario de Investigaciones y Estudios sobre Medio Ambiente y Desarrollo (CIIEMAD, IPN); Instituto de Ingeniería (II, UNAM) Tecnológico Superior de Felipe Carrillo Puerto (TecNM Campus Carrillo Puerto)
Advanced Materials	N=8 320; 330; 340; 380; 540; 1590; 1890; 1920	CICY; Centro de Física Aplicada y Tecnología Avanzada (CFATA, UNAM)
Bioremediation and purification mechanisms	N=4 460; 550; 560; 1950	CFATA; UPQROO

5.1.Agriculture industry and livestock goods

Compost

In Mexico, the private sector led by the Moon Palace Hotel, was one of the pioneers in using *Sargassum* as compost (Supplementary File 1). This hotel in Quintana Roo has developed a sustainable research and development program to reduce its carbon footprint (https://www.palaceresorts.com/es/low-carbon-y-sustentabilidad). Among the initiatives of this program there is an area dedicated exclusively to *Sargassum*, where its utilization, from composting to the development of biodiesel, has been explored.

Agricultural substrates

A group of researchers from the ITConkal has conducted physical and chemical characterization studies of organic materials for agricultural substrates, including *Sargassum*. This group found that *Sargassum*-based substrates contain considerable amounts of potassium and magnesium, but also considerable amounts of sodium, which makes these substrates difficult for plant cultivation unless highly effective desalinization procedures are used [71,92]. The ITCH and CP Campus Puebla have focused research efforts to determine the effectiveness of *Sargassum* as a substrate for the growth of commercial fungi. They have determined that fungi of the *Pleurotus* genus can be inoculated and grow, develop and reproduce on a *Sargassum*-based growth substrate [93].

Biopesticides and bioprotectors

The UPAEP has evaluated *Sargassum* for this use by means of phytochemical, bromatological, herbicidal and toxicological tests (Supplementary File 1) but no publications are yet available.

Biostimulants and biofertilizers

The potential use of *Sargassum* as a biofertilizer has become visible in Mexico through several consolidated companies, making it one of the most promising and best studied uses of *Sargassum*. The companies Alquimar, Dianco, Salgax, Dakatso and C-Combinator have developed biofertilizers.

5.2.Chemistry, pharmaceutics and nutritional supplements

Alginates

The extraction of alginates from *Sargassum* has been conducted by several research groups and consolidated companies in Mexico, being one of the most promising and best explored uses, along with the development of biofertilizers. In the private sector, the companies Metco, Creamos Más, and Alquimar have developed marketable products. In academia, the Tecnológico de Monterrey, the Universidad de Quintana Roo and CICY have developed successful processes for the extraction of alginates (Supplementary File 1).

Fucoidans

Creamos Más and Alquimar companies have patented their processes for the extraction of fucoidan from *Sargassum*. Alquimar markets a food supplement based on fucoidan extracted from *Sargassum*. In academia, CINVESTAV has studied the effects of fucoidans and alginates extracted from *Sargassum* in antiviral activity against herpes virus type I *in vitro* with promising results [94]. The Universidad de Quintana Roo and the CICY have also developed successful fucoidan extraction processes (Supplementary File 1).

Fucoxanthin

The Universidad La Salle has led research efforts in this area and have developed fucoxanthin extraction processes from *Sargassum* [77].

5.3.Ecomaterials

Materials for bioconstruction

The company BlueGreen commercializes bricks made with *Sargassum* and has even built prototype houses [119]. Dakatso company has developed a type of concrete from *Sargassum* called "Sargacreto". In academia, the UIIM have studied the thermal conductivity of *Sargassum* and its characterization by scanning electron microscopy for the identification of compounds such as calcite and other fibrous materials that support the use for bioconstruction [97]. CICY has also developed sheets for construction made from a mixture of *Sargassum* and recycled plastic [96].

Textile fibers

In Mexico, the company Renovare has developed and commercialized footwear containing cellulosic fibers from *Sargassum*.

Bioplastics

In Mexico, the companies Abaplas and Energryn began the development of bioplastics with ~30% content *Sargassum* in their manufacture. The company Dianco has also

conducted processes to transform *Sargassum* into bioplastics, although its only commercial products to date are biofertilizers. In academia, UNADM developed a biopolymer from *Sargassum*, with similar characteristics to those of conventional plastics [98].

Cellulose and paper

In Mexico, Dianco company has used *Sargassum* for cellulose extraction and paper manufacturing, while the company Sargánico created sustainable products such as notebooks, agendas, folders, cup holders, menu holders and business cards, among others.

5.4.Livestock feed

Due to potential toxic effects of heavy metals from *Sargassum*, the only identified ongoing effort on this topic is conducted by CICIMAR. This research explores the use of *Sargassum* as food for laying hens. The hypothesis of this research is that a *Sargassum*-based diet would produce a iodine biofortified egg with low cholesterol content.

5.5.Bioenergetics

Bioethanol

In Mexico, this process has not been developed by the private sector. There are some initiatives in academia that have shown the potential of this use. For example, a group of researchers from the UAdeC successfully produced bioethanol from *Sargassum* using a pretreatment with high pressure technology [99,100].

Biogas

Initiatives for the generation of biogas from *Sargassum* biomass within the private sector have been conducted by the companies Grupo Transportación Marítima Mexicana (TMM) and Nopalimex. In academia, the Universidad La Salle and CICY are the only institutions that have published articles about this topic. They concluded that there is a promising potential of *Sargassum* for biomethane production [81].

Biodiesel

The only effort to produce biofuel from *Sargassum* in Mexico was conducted by a group of students of the TecNM Campus Carrillo Puerto, who developed a product prototype (TRL = 3) and created a company called Bioremar.

Combustion

The company G2E and the II, UNAM have conducted research for the generation of electric energy via hydrothermal carbonization of *Sargassum*.

5.6.Advanced materials

The CICY is the institution with more advances in this area. They concluded that *Sargassum* is a promising source of biocarbon for the generation of electrocatalysts that can be used in the development of fuel cells that convert chemical energy into electrical energy. This institution also synthetized platinum nanoparticles (PtNP) using an aqueous extract of *Sargassum* [85–86,103,121]. Other related research has been conducted by the Centro de Física Aplicada y Tecnología Avanzada (CFATA), UNAM where they conducted a green synthesis of gold nanoparticles from *Sargassum*. These nanoparticles were used to modify a screen-printed electrode with carbon nanotubes to assemble a new portable electrochemical glucose sensing platform [101]. Similar research conducted by the same institution used *Sargassum* extracts for the green synthesis of silver nanoparticles. These nanoparticles have significant catalytic activity for the degradation of blue methylene and have effective antibacterial activity against *Staphylococcus aureus* and *Pseudomonas aeruginosa* [102].

5.7.Bioremediation and purification mechanisms

In Mexico, the exploration of this potential use of *Sargassum* is recent and exclusive to academic research by the CFATA, UNAM and the UPQROO. These groups have evaluated the effectiveness of a *Sargassum*-based bioremediation system for the removal of metal ions and toxic dyes from water, reaffirming the potential for industrial scale-up of these bioremediation systems [104].

6. Regulations and other strategic lines

In Mexico, the "Lineamientos Técnicos y de Gestión para la Atención de la Contingencia ocasionada por sargazo en el Caribe Mexicano y el Golfo de México" is the only document available of its kind, published and updated by SEMARNAT in 2021. These guidelines, which are not mandatory, establish the technical specifications for open sea harvest, containment by barriers, removal on beaches, treatment prior to final disposal, final disposal and quantification of *Sargassum* for monitoring purposes [69].

Among the strategies identified in the Communication and Education strategic line are various articles, specialized magazines, websites of different federal government agencies (e.g., CONACYT's microsite about *Sargassum* (https://conacyt.mx/sargazo/) and mobile applications (e.g., SargaZoom) (Supplementary File 1).

Within the international cooperation strategic line important international alliances have been developed from Mexico. For example, in 2020, Mexico joined SargCoop, an international consortium that was created at the International Conference on *Sargassum* held in the Guadeloupe region of the West Indies in 2019. The objective of this consortium is to strengthen cooperation among the Caribbean countries to protect the oceans and the environment, as well as to promote the exchange of knowledge, experience and existing tools to address this *Sargassum* phenomenon in a comprehensive manner [105].

Finally, the extent of the environmental impact of *Sargassum* influxes, especially outside of tourist areas, is not known at this time. Efforts to restore and rehabilitate ecosystems affected by influxes have not been documented in Mexico.

References

113. Rosado-Espinosa, L.A.; Freile-Pelegrín, Y.; Hernández-Nuñez, E.; Robledo, D. A comparative study of *Sargassum* species from the Yucatan Peninsula coast: Morphological and chemical characterization. *Phycologia* **2020**, *59*, 261–271.
114. López Zenteno, A. *Acciones para la Atención del Arribo Masivo del Sargazo en Aguas Mexicanas. Seminario-Taller Online Nacional Sobre Teledetección, Monitoreo, Pronóstico y Alerta Temprana del Sargazo Pelágico que Arriba a las Costas Mexicanas: Descubriendo Sinergias y Construyendo Puentes Hacia un Sistema Integral y Regional*; CONACYT: Mexico City, Mexico, 2021.
115. Uribe-Martínez, A.; Cuevas, E. *Detección de Sargazo con Imágenes de Alta Resolución Espacial para la Estimación de Patrones Locales. Seminario-Taller Online Nacional Sobre Teledetección, Monitoreo, Pronóstico y Alerta Temprana del Sargazo Pelágico que Arriba a las Costas Mexicanas: Descubriendo Sinergias y Construyendo Puentes Hacia un Sistema Integral y Regional*; CONACYT: Mexico City, Mexico, 2021.
116. Salinas, J.A.; Maya-Magaña, M.E.; Hernández-Martínez, C. *Diagnóstico de las Condiciones Atmosféricas Asociadas al Arribo de Sargazo a Costas de Quintana Roo*; Research Internal Project; IMTA, Jiutepec, Morelos, Mexico: 2019; 39p.
117. Sayas-Herazo, M.; Ramos-Díaz, A. Shock sistémico por *Shewanella putrefaciens*: Reporte de caso. *Acta Colomb. Cuid. Intensivo* **2021**, *21*, 334–337.
118. El Imparcial. Voluntarios Recolectan 48 Toneladas de Sargazo en Playas de QR. 2019. Available online: https://www.elimparcial.com/mexico/Voluntarios-recolectan-48-toneladas-de-sargazo-en-playas-de-QR-20190527-0006.html (accessed on 21 October 2021).
119. Notired. Las Multas que se Pueden Pagar Levantando Sargazo en Cancún. 2019. Available online: https://www.notired.info/?p=9379 (accessed on 21 October 2021).
120. La Jornada. Tres empresas se convierten en emblema en pro del medio ambiente. 2019. Available online: https://www.jornada.com.mx/2019/07/21/economia/016n1eco (accessed on 21 October 2021).
121. Rosas-Medellín, D. Utilización del *Sargassum* spp. para Síntesis Verde de Nanopartículas de Platino y Producción de Carbón para Aplicaciones en la Generación de Energía. Master's Thesis. CICY, Mérida, Yucatán, Mexico, 2019.