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Identification of applicable regulation and public policy gaps regarding marine renewable energy in Mexico

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ABSTRACT

Integrating renewables into the energy matrix enables efficient energy systems and meets the UN Sustainable Development Goals 7) affordable and clean energy, 9) industry, innovation, and infrastructure, 12) responsible production and use, and 13) climate action. A specific case is the use of marine renewable energy (MRE) for power supply in coastal cities affected by environmental and anthropogenic threats. MRE can be harnessed from waves, currents, offshore wind, and thermal and salinity gradients. In emerging economies, the marine renewable energy industry is at different stages from quantifying the potential, to device development, or testing. Currently, in Mexico, there is a wide range of marine energy projects despite the technological advances there is no framework for the device's deployment.

As a guide for developers, this article presents the current Mexican legislation on MRE. The review of the legislation has identified some niche opportunities that were highlighted during the research; legal pathway for planning and operational purposes.

1. Introduction

In response to climate and energy crises due to an increase in global average temperature, changes in precipitation patterns, and sea level rise Alemán-Nava et al., 2014, many countries have implemented strategies seeking carbon neutrality (eliminating anthropogenic CO2 emissions during a specific period; UNFCCC 2021). The use of fossil fuels is unavoidably degrading the environment, which, in addition to the volatility of fuel prices, exacerbates energy scarcity and has led many countries to take serious action. Among the efforts to achieve this goal is the transition to clean energy sources and low ecological footprint means of production Apolonia et al., 2021. However, the energy matrix's diversification process has been slow in emerging economies despite the available power and technological progress of renewable energy (RE) conversion (Berkhout et al., 2012). Due to the variety of ecosystems, social and cultural diversity, funding opportunities, and the political situation (Posada et al., 2019; Felix et al., 2019), thus the guidelines for the marine renewable industry must consider site-specific criteria that are not found in countries where the industry is at an advanced stage Bracho et al., 2021.

A particular case that attracts special attention is harnessing marine renewable energy (MRE) Taormina et al., 2018. The oceans represent a vast reservoir of power, and its harnessing could supply local demands. However, some studies (Berkhout et al., 2012; Dong et al., 2021; Blohm, 2021) argue that MRE must overcome non-technical, political, economic, and social challenges to achieve the transition Baring-Gould et al., 2016.

From the administrative point of view, the main obstacles to the MRE industry are the lack of coordination between authorities regulating the coastal and marine zone and regulatory, administrative, and financial barriers (Simas et al., 2012; Yang et al., 2019 For example Shetty and Priyam, 2022, the AWS project in Portugal required 26 permits from 10 federal, state, and local institutions for its implementation. This example emphasizes the relevance of public policies in establishing new industries Berkhout et al., 2012, as they must be viable and long-term to generate confidence and attract investors, in addition to encouraging the monitoring of electricity industry activities (Leete et al., 2013). Mexico is emerging as one of the countries with the greatest opportunity to benefit from MRE (Hernández-Fontes et al., 2019). The potential assessment indicates this resource can be part of the energy matrix, thus could support the energy demand in coastal cities or help to provide electricity for basic needs in isolated communities (Ventura et al., 2022;

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Hernández-Fontes et al., 2020; Gorr-Pozzi et al., 2022).

Despite the recognized potential of renewable energy sources for electricity generation in Mexico, in the last 15 years, natural gas has been the preferred option Copping et al., 2020. Nevertheless, oil and natural gas reserves are declining (IRENA, 2020), therefore raising energy production costs. Mexican legislation on RE began in late 2008, yet the process of permitting, institutional participation, incorporation into the national electricity grid, and monitoring remains uncertain García-Santiago et al., 2022. Additionally, political instability and the rules imposed by the state-owned power generation and transmission company have slowed down the development of the renewable electricity industry in Mexico (Apolonia et al., 2021; Leete et al., 2013; Alemán--Nava et al., 2014;Dalton et al., 2009). Better coordination between licensing authorities and developers would facilitate the incorporation of MRE into the energy matrix (Salvador et al., 2019).

For Mexico to incorporate MRE in the electricity industry, it is necessary to have a thorough understanding of the regulatory framework to which this part of the industry is subject Genave et al., 2020. This knowledge provides two benefits: the first is to facilitate obtaining permits or licences for the development of projects, favouring good coordination with the authorities Ibrahim et al., 2022. Secondly, it gives certainty to financing entities (Vazquez et al., 2015). Given that the administrative process needed to achieve the implementation of MRE projects in Mexico is not well documented, this research aims to present an overview/guide of the applicable regulations to be considered in the planning and application for permits to place marine energy plants intended to reach the end users REN21, 2020.

2. Methods

Based on the available information on the theoretical potential of marine energy we identified the sources that can be exploited, according to the classification of marine energy devices (Fig. 2) characteristics and requirements for their deployment this information was used to guide the search of the gaps in the legislative framework.

Mexico has laws for the development of RE, in this case, the permits and licensing presented focus on the current renewable energy legislation Quirapas and Taeihagh, 2021. An exhaustive analysis of the legislative framework for a) the electrical industry, b) environmental and social impact assessment, c) laws and regulations of the Mexican coastal marine zone was carried out BOEM, 2014.

The objective was to identify the procedure to be followed for the siting of energy infrastructure in the coastal zone. This analysis made it possible to determine the legal elements that apply and that favor or limit the implementation of MRE projects. Finally, the steps in the current regulatory framework are summarized.

2.1. Energy legislative framework: Mexico

The Mexican coast comprises 1 108 766 km^2, representing 56.36% of the national surface (Zarate, 2004), the country is surrounded by two oceans which gives an important biological richness both in the terrestrial and marine ecosystem.

These characteristics give a wide variety of resources that can be exploited for the generation of energy from renewable sources (Grottera, 2022). In this context, renewable energy could play an important role in the economic and energy system in Mexico. Therefore, the government established the Pact for Mexico in 2012 Boehlert and Gill, 2010. This agreement called for intensifying economic competition in the energy sector (del del Río Monges et al., 2016). In this context, renewable energy could play an important role in the economic and energy system in Mexico Villate et al., 2020. Therefore, the government established the Pact for Mexico in 2012. This agreement called for intensifying economic competition in the energy sector QRooGov, 2021.

Due to the relevance of the articles, their purpose will be briefly mentioned; the first article is commissioned for the planning and control

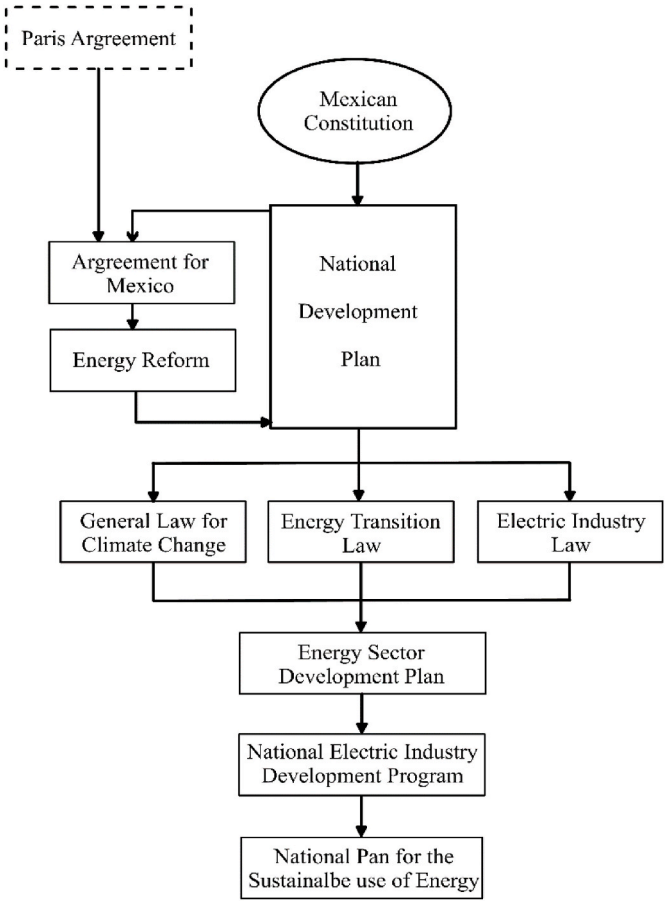

Fig. 1. Elements of Mexican policy regulating the energy sector, including marine energy as a renewable source.

of the national electric system and the public service, as well as the exploration of resources. Article 27 corresponds to the Nation the dominion of the natural resources of the continental platform and the use but through concessions granted by the federal executive, while Article 28 mentions that there will be regulatory bodies in energy matters.

This was a turning point that prompted the modification in the energy sector, hence the approval of the Energy Reform, the National Development Plan, and the Electricity Industry Law whose overall objectives are a) modernization of the energy sector and maintaining the competitiveness of the productive sectors. The Mexican regulatory structure described so far is shown hierarchically in Fig. 1.

Subsequently, the Energy Transition Law was passed, its purpose is to regulate the sustainable use of energy, as well as the obligations regarding clean energy and the reduction of polluting emissions. In this regard, the National Development Plan 2020–2024 introduced a section on rescuing the energy sector to promote sustainable development based on RE and mentioned it as a driver of investment and growth. The Energy Reform introduced the Clean Energy Certificates scheme, establishing the mandatory use of clean energy and reducing pollutant emissions.

The MEI should consider the provisions in the General Law on Climate Change, the Energy Sector Development Plan, the National Electricity Industry Development Program, and the National Plan for the Sustainable Use of Energy. The Mexican regulatory structure described so far is shown hierarchically in Fig. 1.

Given their location and the areas in which they will operate legal issues may arise regarding terrestrial planning, offshore installation, and environmental and social constraints (Adimazoya and Doelle, 2021), thus MRE projects in Mexico require the cooperation of local, state, and

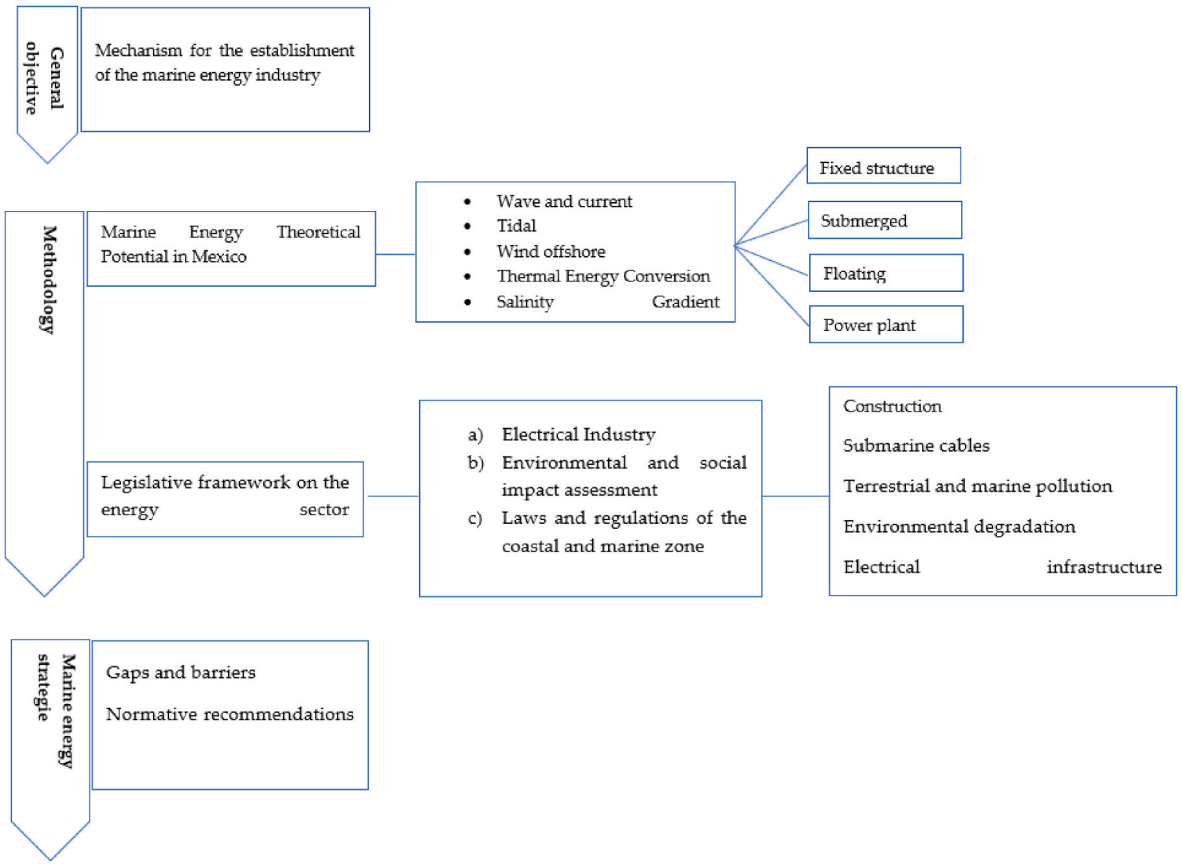

Fig. 2. Steps for the analysis of the legislative framework for the marine energy devices.

federal governments Adimazoya and Doelle, 2021. Table 1 presents the Mexican institutions authorizing permits, concessions, and licenses for energy sector infrastructure with their corresponding administrative order.

Although coastal Mexican states have energy initiatives an analysis of the legal framework is required to identify the barriers and pathways to enable the deployment of marine energy. Here we present the energy legislation per state in Table 2.

3. Results

As a result of the literature review, Table 3 shows a compendium of possible environmental stressors and their corresponding receptors related to the placement of marine energy conversion devices in Mexico, i.e. the selection of the marine energy resource will have a stressor that has a receptor that based in the magnitude may have an impact in the environment this in turn, can be temporary, occupy a significant area or add to the current impacts. Based on this information, the impact of each aspect was estimated, and the applicable regulations for each type of technology were determined.

Tegner Anker et al. (2009) raise critical questions about the jurisdiction of MRE projects, including questions about the exercise of

Table 1
Federal, state and local government entities involved in MRE projects licensing in Mexico.

Administrative order	Government entities	Authorizing permits
Federal	SEMARNAT	Environmental impact assessment and permit for construction
	SENER	Social impact assessment and permit to generate electricity in national territory
	CRE	Electricity network interconnection contracts Permit for supplier modality
	CONAGUA	Industrial wastewater discharge permit
	PROFEPA	Compliace of environmental legal provisions
State	CONAFOR	Conservation of forest and environmental services (mangroves)
Local	Local territorial planning institutions	Urban and territorial planning Construction permits

Table 2
Energy legislation per state in Mexico (CONUEE, 2023).

State	Energy legislation
Baja California	Ley de Impulso para la Eficiencia Energética
Chihuahua	Ley para la promoción, aprovechamiento y desarrollo de la Eficiencia Energética y las Energías Renovables
Coahuila	Ley de fomento del uso racional de la Energía
Colima	Ley para el fomento de las Energías Renovables y la Eficiencia Energética
Durango	Ley para el fomento y aprovechamiento de las Fuentes Renovables de Energía
Guanajuato	Ley para el fomento del uso de las fuentes renovables de energía y la sustentabilidad energética para el Estado y municipios de Guanajuato
Hidalgo	Ley para el Fomento del Ahorro Energético y uso de Energías Renovables
Oaxaca	Ley de Coordinación para la promoción del uso sostenible de las fuentes de energía renovables
Quintana Roo	Ley para el fomento y aprovechamiento de las Fuentes Renovables de Energía
Sonora	Ley de Fomento de las Energías Renovables y Eficiencia Energética
Tamaulipas	Ley para el aprovechamiento de las Energías Renovables

Table 3
Estimated environmental impact of Tidal energy (TE), Wave Energy (WE), and Offshore Wind (OW). With information from (Boehlert and Gill, 2010; Hutchison et al., 2022; Martínez et al., 2021; Shetty and Priyam, 2022; Copping et al., 2020).

Marine Renewable Energy (Level 1)									
TE			**WE**			**OW**			
Energy produced from the force of the wind at high seas			Energy harvested from the motion of waves			Energy produced from the movement of tides			
Device Type:Horizontal axis, vertical axis, oscilating hydrofoils			Device Type: oscilating wave surge/water column			Device Type: Horizontal axis, vertical axis			
Device Location: Submerged/Seabed-mounted, Floating & water column			Device Location: Submerged/Seabed-mounted & Floating			Device Location Tension leg Platform, Floating, Semi-submersible, Spar-buoy			
Complementary elements: Converter, Transformer, Underwater cables, Substation, distribution network									
Environmental Stessors (Level 2)									
Physical Presence of Devices		Dynamic Effects of Devices		Energy Removal Effects		Acoustic		Electromagnetic Fields	
Environmental Receptors (Level 3)									
Physical Environment	Pelagic Habitat	Benthic Habitat and Species	Fish and Fisheries	Marine Birds		Marine Mammals		Ecosystem and Food Chain	
Environmental Effect (Level 4)									
Noise	Collision	Habitat Change	Wave or Tidal modifications	Electromagnetic	Hydro Sedimentary	Artificial Reef Generation	Water Quality	Entrapment	Pollution
Environmental Impact (Level 5)									
Population Change			Community Change		Biotic Process Alteration			Physical Structure/ Process Alteration	
Cumulative (Level 6)									
Spatial			Temporal			Other Human Activities			

regulatory power, i.e., do local, regional or federal authorities govern it? The countries where these technologies have been developed modified their policies to facilitate permitting (Tegner Anker, 2009). For example, in the UK, the Planning Act 2008 and the Marine and Coastal Access Bill stipulate how to acquire permits for marine energy projects (Gibson and Howsam, 2010).

The main barriers for each MRE technology are described below based on the environmental stressors shown in Table 2.

3.1. Tidal energy (TE)

The Technology Readiness Level (TRL) of the most successful TE devices currently varies between 7 and 9 (Nachtane et al., 2020; Si et al., 2022). Although this technology features a high degree of maturity, there are no clear regulations regarding its implementation in Mexico BOWind, 2008. Some of the rules that apply to the installation of current devices are the following: Reglamento de la Ley de Aguas Nacionales, Reglamento para el Uso y Aprovechamiento del Mar Territorial, Vías Navegables, Playas, Zona Federal Marítimo Terrestre y Terrenos Ganados al Mar, NOM-001-SEDE-2012, Reglamento LEEGEPA, NMX-AA-120_SCFI-2016, NOM-146-SEMARNAT-2017, NRF-048-PEMEX-2007, NRF-013-PEMEX-2001, NRF-033-PEMEX-2010 y NRF-153-PEMEX-2009 (Table 5).

Compliance with these standards can be summarized in the following actions: identifying the type of device, its location, the organization of the space, and determining the type of generation (self-consumption, cogeneration, small production, independent production, or grid connection).

In some cases, the generation capacity sets the regulations to be followed as well as the cost of permits and licensing. For example, in Nova Scotia, Canada, there are two types of permits: testing devices and demonstration. The first type involves deploying one or more devices, and only if the project can generate 15 MW or more, it moves to the demonstration type (NSGov, 2012). According to the phase (testing, pre-commercial, and commercial), the requirements will scale up. The license type is an important aspect, but absent in Mexican regulations.

3.2. Wave energy (WE)

Wave energy faces two types of legal challenges 1) the space that the project will occupy and 2) the regulation of its use when interacting with protected natural areas, shipping, fishing and other industrial and tourism activities (Borges Posterari and Waseda, 2022). Regarding the first point, the selection of the devices, by their installation site, can be onshore, nearshore, or offshore. The main aspect determining the marine area occupied is the number of devices deployed to achieve the project's installed power. In turn, it must be established whether the devices will be fixed to determine the interactions with other activities. In any case, oil exploration and exploitation rules can serve as a guideline for wave energy conversion facilities.

In terms of the construction of oil platforms it is necessary the design and location of the infrastructure, seabed inspection, planning the transport operations; in case of ship use it is necessary to inform the Navy Secretary for the coordination of the activities and follow the guidelines of the environment impact assessment for the terrestrial and marine zone.

Among the provisions for the exploration and exploitation of hydrocarbons is the responsibility of the permit holder in the event of damage to the environment and the economic activities with which they share territory.

Other standards applicable to WECs include the transport of energy, regulated by NOM-001 SEDE-2012; NOM-059-SEMARNAT-2010, NOM-162-SEMARNAT-2012, NOM-022-SEMARNAT-2003, NMX-AA-120_SCFI-2016. NOM-146-SEMARNAT-2017 allows for the identification of fauna in the area and the assessment of impacts on the siting, functioning and operation of devices; PEMEX reference standards (NR) on the construction, installation and protection of offshore facilities NRF-053, NRF-106, NRF-153 and NRF-173. Three standards, NRF-003-PEMEX-2000 concerning the design and evaluation of platforms and NRF-048-PEMEX-2007 and NRF-013-PEMEX-2001 regulating the installation of submarine lines, which apply only in the Gulf of Mexico, could be used as a basis for the creation of standards at a national level (Table 5).

3.3. Offshore wind (OW)

Offshore wind energy conversion is the most developed MRE, as devices and plants feature TRL 8 and 9 (Ibrahim et al., 2022).

Before establishing the applicable regulations, it is necessary to verify what type of devices will be used in the project, i.e. fixed platforms, floating devices or vessels. Subsequently, it is required to consider the regulations related to navigation routes (NOM-002-SCT4-2013); transport of components (Reglamento para el Transporte Terrestre de Materiales y Residuos Peligrosos); noise increase in both land and marine areas (NOM-081-ECOL-1994) and the location of submarine cables (NRF-106-PEMEX-2010) Hutchison et al., 2022.

The spatial configuration of offshore wind farms (OWFs) is essential

Table 4
SG and OTEC environmental stressors and receptors (Boehlert and Gill, 2010; Hutchison et al., 2022; Martínez et al., 2021; Shetty and Priyam, 2022; Copping et al., 2020).

Marine Renewable Energy (Level 1)									
SG					**OTEC**				
Salinity gradient energy is the energy extracted at the junction of two water sources with different salt concentrations.					Solar energy conversion system for producing electricity, using warm and cold ocean layers to vaporize and condense a fluid that drives a turbine				
Device Type: Membrane Modules*					Device Type: OTEC system**				
Device Location: Land, floating and offshore					Device Location:Land, floating and offshore				
Complementary elements Converter, Transformer, Underwater cables, Substation, Distribution network, Underwater pipes					Complementary elements: Converter, Transformer, Underwater cables, Substation, Distribution network, Underwater pipes				
*Pumps, Turbine					**Condenser, Evaporator,Turbine, Generator, Pump				
Environmental Stessors (Level 2)									
Pollutants	Land Modification	Physical Infrastructure	Chemical	Acoustic	Effluent discharge	Water Intake		Infrastructure modification	
Environmental Receptors (Level 3)									
Physical Environment	Pelagic Habitat	Benthic Habitat and Species	Fish and Fisheries	Marine Birds	Marine Mammals			Ecosystem and Food Chain	
Environmental Effect (Level 4)									
High Intensity sounds	Habitat Removal	Sediment Runoff	Release of Pollutants	Increase in noise level	End water diversion, intake, and discharge	Impingement and entrainment	Water current disruption	Change water propeties at discharge site	Treatment chemicals released at discharge site
Environmental Impact (Level 5)									
Population Change		Community Change		Biotic Process Alteration	Physical Structure/Process Alteration		Reef-like habitat created		
Cumulative (Level 6)									
Spatial			Temporal		Other Human Activities				

to know the project requirements (Skousen et al., 2018). Being on platforms, the regulations that can be followed are similar to those stipulated for oil exploration and development and wind turbine regulations in wind farms. The principal regulations in this respect in Mexico were mentioned in the section on wave energy.

3.4. Salinity gradient energy (SGE)

The regulations that must be considered to implement this technology are those governing the permissible limits of pollutants, pollutant control, and environmental protection of native species as follows: Reglamento de la Ley de Aguas Nacionales, NOM-001-SEMARNAT-2021 and NOM-002-SEMARNAT-1996 which establish the permissible limits of pollutants in wastewater discharges in property of the nation and in sewage systems and NOM-059-SEMARNAT-2010, NOM-162-SEMARNAT-2012, NOM-022-SEMARNAT-2003, NMX-AA-120_SCFI-2016 which sets environmental protection to Mexican native species of wild flora and fauna.

The assessment of environmental and social impacts, permits and obligations of the project developer can follow the regulations developed for desalination plants, which focus on the dispersion and contamination of toxic substances in water bodies. In this respect, there is the Reglamento para prevenir y controlar la contaminación del Mar por Vertimiento de Desechos y otras materias; the Reglamento para el transporte Terrestre de Materiales Residuos peligrosos, and the NOM-052-SEMARNAT-2005 which establishes the procedure for the identification, classification and listing of hazardous wastes.

In addition, the NOM-001-SEMARNAT-2021 and NOM-002-ECOL-1996 clarify the permissible limits of pollutants in discharges, as well as regulate the preservation and control of water quality with the Reglamento de la Ley de Aguas Nacionales. The construction phase in the terrestrial zone represents permanent impacts; in this phase, the instruments that regulate the emission of greenhouse gases are the Reglamento de la Ley General de Cambio Climático en Materia del Registro Nacional de Emisiones, and the NOM-081-ECOL-1994.

3.5. Ocean thermal energy conversion (OTEC)

OTEC plants can be located onshore or floating at sea. In both cases, the discharge regulations are similar to those for SGE. Among the most important aspects to assess are the geometry and effects of the discharge plume ruled by the NOM-001-SEMARNAT-2021 and the NOM-002-ECOL-1996 NOM-003 (Papapetrou and Kumpavat, 2016).

In the case of offshore OTEC plants, the existing standards that apply are those mentioned in wave energy, taken from the oil industry.

The SGE and OTEC energy sources are at a lower degree of technological development, and they keep some similarities due to having an intake and a discharge; therefore, they are presented separately from TE, WE and OW. Table 4 shows the environmental stressors and receptors that determine the applicable regulations for these two technologies.

3.6. Guidelines for marine energy projects in Mexico

Soukissian et al., 2017 mention marine spatial planning (MSP) as a tool to enable the sustainable use of resources by analysing and allocating spatiotemporal patterns of anthropogenic activities with a holistic approach. In other words, a document containing guidelines for developing MSP projects considering current uses, as well as encouraging funding mechanisms (Soukissian et al., 2017). Ghazali and Mustafa, 2020 confirm the importance of MSP in supporting the development of MRE projects (Ghazali and Mustafa, 2020).

As a summary and tool for the reader, Table 5 presents a compendium of the abovementioned regulations, the energy sources for which they apply, and some general specifications of each.

Fig. 3 shows the general criteria that should lead marine energy development plans, including technological, environmental, social and

Table 5
Energy sector policies applicable for the MRE projects implementation. SG = salinity gradient, OTEC = ocean thermal energy conversion, TE = tidal energy, OW = offshore energy, and WE = wave energy.

Legislation	Date of creation and modification	Definition	Specifications	MRE applicable to
Ley general para la prevención y gestión integral de los residuos.	Date of creation: October 8, 2003 Date of modification: May 8, 2023	It refers to the protection of the environment in terms of prevention and integrated waste management in the national territory.	Provisions whose purpose is to guarantee the right of every person to a healthy environment and to promote sustainable development; to prevent contamination of sites and to carry out its remediation.	SGE OTEC TE OW WE
Ley general del equilibrio ecológico y la protection al ambiente.	Date of creation: January 28, 1998 Date of modification: January 24, 2024	It refers to the preservation and restoration of the ecological balance and the protection of the environment in the national territory and the zones over which the nation exercises its sovereignty and jurisdiction.	It specifies the preservation and, where appropriate, the restoration of soil, water and other natural resources, in such a way that the obtaining of economic benefits and the activities of society are compatible with the preservation of ecosystems.	SGE OTEC TE OW WE
Ley de la industria eléctrica.	Date of creation: August 11, 2014 Date of modification: May 11, 2022	Promotes the sustainable development of the electricity industry and guarantees its continuous, efficient and safe operation for the benefit of users, as well as compliance with the obligations of universal public service, clean energy and the reduction of polluting emissions.	Specifications on the activities of generation, transmission, distribution, commercialisation and the Operational Control of the National Electricity System are of public utility and will be subject to universal public service obligations.	SGE OTEC TE OW WE
Ley de aguas nacionales	Date of creation: December 1, 1992 Date of modification: May 8, 2023	Regulates the use or exploitation of national waters, their distribution and control, and the preservation of their quantity and quality to achieve sustainable development.	Coordinates the planning, execution and administration of water resources management actions.	SGE OTEC TE OW WE
Ley de Transición energética	Date of creation: December 24, 2015	Its purpose is to regulate the sustainable use of energy as well as the obligations in terms of Clean Energies.	It specifies that the consumption of electricity should be affordable for all through a portfolio of alternatives, including clean energies.	SGE OTEC TE OW WE
Ley de Vertimientos en las Zonas Marinas Mexicanas	Date of creation: January 17, 2014 Date of modification: April 13, 2020	It aims to control and prevent pollution or alteration of the sea by dumping in Mexican marine areas.	Specifications on discharges into the Mexican marine zone. It governs the marine zones of Mexico.	SGE OTEC TE OWF WE
Ley federal del Mar	Date of creation: January 8, 1986	Rules all Mexican marine areas.	Article 6. The national legislation is applicable to: IV. The economic exploitation of the sea, including the utilisation of minerals dissolved in its waters, the production of electrical or thermal energy derived from the same, from currents and winds, the capture of solar energy in the sea, the development of the coastal zone, mariculture, the establishment of national marine parks, the promotion of recreation and tourism and the establishment of fishing communities.	SGE OTEC TE OW WE
Ley general de cambio climático	Date of creation: June 6, 2012 Date of modification: November 15, 2023	Regulation in the field of addressing the adverse effects of climate change.	Provisions for dealing with the adverse effects of climate change in the form of environmental protection, sustainable development, preservation and restoration of ecological balance.	SGE OTEC TE OW WE
Ley Federal de Responsabilidad Ambiental.	Date of creation: Date of modification:	Environmental liability arising from damage caused to the environment, as well as repair and compensation for such damage.	Specifications on environmental regulation and liability arising from damage to the environment.	SGE OTEC TE OW WE
Reglamento de la Ley de Aguas Nacionales	Date of creation: June 7, 2013 Date of modification: May 20, 2021	The regulation on the preservation and control of water quality.	Article 20.- Any activity that implies the exploitation, use and economic exploitation of Mexican marine areas.	SGE OTEC TE Offshore WE
Reglamento para prevenir y controlar la contaminación del Mar por Vertimiento de Desechos y Otras Materias	Date of creation: January 23, 1979	Controls the discharges of such dumping, subject to the principles, requirements and conditions established to prevent the risk and damage that may be caused to the ecological balance.	Article 1.- It shall apply to deliberate discharges of waste substances in Mexican maritime waters. Article 10.- No permit shall be granted for discharges that alter the standards and quality of water or that endanger human health, welfare or the marine environment, ecological systems or economic potentialities and that affect recreational areas such as beach resorts, marinas and sports areas Article 12.- The opinions of the corresponding institutions or agencies that	SGE OTEC TE OW WE

(*continued on next page*)

Table 5 (*continued*)

Legislation	Date of creation and modification	Definition	Specifications	MRE applicable to
			may determine their feasibility or inappropriateness must be taken into account. Article 13.- In order to obtain a dumping permit, the substances must comply with the following characteristics:a) Rapidly degrade into innocuous substances, which by the physical, chemical or biological procedures to which they have been previously subjected, do not contaminate or alter the taste of edible marine organisms, so that they do not represent a danger to human or domestic animal health.b). If traces of other substances are found within the waste or substance permitted to be discharged, the quantity of substance to be discharged shall be indicated to calculate whether these traces may become harmful due to the quantity of discharge.	
Reglamento para el Uso y Aprovechamiento del Mar Territorial, Vías Navegables, Playas, Zona Federal Marítimo Terrestre y Terrenos Ganados al Mar	Date of creation: August 21, 1991	Its purpose is to administratively and legally provide for the use, exploitation, control, administration, inspection and surveillance of the beaches, federal maritime-terrestrial zone and land reclaimed from the sea or any other deposit formed with maritime waters and of the assets that form part of the port enclosures that are destined for maritime-port installations and works.	Article 3: Delimitation of the federal maritime-terrestrial zone. Article 5: Request concessions, permits and authorisations for the use, exploitation, occupation and construction of works in the territorial sea, beaches, federal maritime-terrestrial zone and land reclaimed from the sea with the Secretariat of Communications and Transport. Article 24.- Necessary steps to grant concessions or corresponding permits for the use and exploitation of the federal maritime-terrestrial zone. Article 29.- Obligations to concessionaires of the federal marine-terrestrial zone.	SGE OTEC TE OW WE
Reglamento LEGEEPA	Date of creation: May 30, 2000 Date of modification: October 31, 2014	Stipulates the rules on pollution control that apply to all aquatic ecosystems, which includes the seas.	Article 5.- Authorisation on environmental impact. Article 13.- Environmental impact assessment. Article 51.- Insurance and guarantees.	SGE OTEC TE OW WE
Reglamento de la Ley de la Industria eléctrica	Date of creation: October 31, 2014	Its purpose is to establish the provisions that regulate the planning and control of the National Electricity System, as well as generation, transmission, distribution and commercialisation activities.	Article 86.- Consultation and evaluation of social impact.	SGE OTEC TE OW WE
Reglamento para el Transporte Terrestre de Materiales y Residuos Peligrosos	Date of creation: April 7, 1993 Date of modification: November 20, 2012	The regulation aims to regulate the inland transport of hazardous materials and wastes.	Specifications on the proper use of transport of hazardous materials.	SGE OTEC TE OW WE
Reglamento de La Ley General de Cambio Climático en Materia del Registro Nacional de Emisiones	Date of creation: October 28, 2014	The regulation specifies the sectors and sub-sectors, as well as the corresponding activities. The regulation lists the greenhouse gases subject to reporting.	Article 5.- Listing of greenhouse gases or compounds. Article 8.- Identification of direct or indirect emissions associated with the consumption of electrical and thermal energy. Articles 12, 13, 14.- Procedure for reporting Greenhouse Gases or Compounds.	SGE OTEC TE OW WE
Disposiciones Administrativas de Carácter General sobre la Evaluación de Impacto Social en el Sector Energético	Date of creation: June 1, 2018	Establishes the elements for the elaboration and presentation of Social Impact and Surface Occupation Assessments.	Article 5.- The promoter shall implement the Social Management Plan, applying a Gender Perspective in a cross-cutting manner. Article 6.- The promoter shall prepare the Assessment with recent, reliable and verifiable information. Article 10.- Formats for the social impact assessment.	SGE OTEC TE OW WE
NMX-J-673-25-3-ANCE-2017	Date of creation: April 21, 2017	Interaction for monitoring and control of wind farms-Information exchange models.	Communications between wind farm components such as wind turbines and actors such as Supervisory Control and Data Acquisition systems.	OW
NMX-AA-120_SCFI-2016	Date of creation: December 7, 2016	Establishes the requirements and specifications for beach quality sustainability	Establishes the requirements and specifications for the sustainability of the quality of play. Establishes the requirements and specifications for quality, health, safety and environmental services for the sustainability of recreational beaches.	SGE OTEC TE OW WE

(*continued on next page*)

Table 5 (*continued*)

Legislation	Date of creation and modification	Definition	Specifications	MRE applicable to
***NRF-003-PEMEX-2000	Date of creation: December 18, 2000	Design and Evaluation of Offshore Platforms in the Campeche Zone.	Establishes the criteria applicable to the design and structural evaluation of fixed platforms in the Campeche area.	TE OW WE OTEC
***NRF-048-PEMEX-2007	Date of creation: July 22, 2003	Design of Electrical Installations.	Establishes the guidelines, criteria and requirements for the design of electrical installations in industrial plants, offices, hospitals, warehouses, workshops and other works of the institution, whether new, extensions or refurbishments.	SGE OTEC TE OW WE
***NRF-013-PEMEX-2001	Date of creation: April 15, 2001	Evaluation of submarine lines in the Gulf of Mexico.	Establishes the parameters, criteria and procedures to be applied for the evaluation of existing submarine lines in the Gulf of Mexico.	SGE OTEC TE OW WE
***NRF-033-PEMEX-2010	Date of creation: August 13, 2018	Concrete ballast for pipelines	Specifications for applying concrete ballast to all types of metallic pipelines with various diameters and thicknesses that transport hydrocarbons, water or nitrogen, submerged in the sea, river crossings, streams, lagoons, marshes or flood zones, where specified according to design.	SGE OTEC TE OW WE
***NRF-053-PEMEX-2006	Date of creation: May 15, 2006	Corrosion protection systems based on coatings for surface installations.	Application for corrosion protection coatings to be used in plants, storage areas, pipeline corridor, offshore platforms.	TE OW WE
***NRF-106-PEMEX-2010	Date of creation: September 17, 2005	Construction, installation and decommissioning of subsea pipelines	Sets out the minimum requirements to be met for subsea pipeline construction, installation and decommissioning services.	SGE OTEC TE OW WE
***NRF-153-PEMEX-2009	Date of creation: June 7, 2009	Corrosion protection coating systems for marine vessels.	Sets out the minimum quality requirements to be met for the inspection, application and testing of corrosion protection coating systems on marine vessels.	SGE OTEC TE OW WE
***NRF-173-PEMEX-2009	Date of creation: June 7, 2009	Design of structural accessories for offshore platforms	This Reference Standard sets out the minimum technical characteristics to be met when contracting the design of structural accessories for offshore platforms.	TE OW WE OTEC
***NRF-186-PEMEX-2007	Date of creation: January 5, 2008	Welding of structural steel for offshore platforms	This Reference Standard establishes requirements for filler materials, weld application, inspection and repair of welded joints of structural steel used in offshore platforms.	TE OW WE OTEC
			***PEMEX Reference Standards	

financial aspects. There, the critical elements of each branch are stressed. The normative tools that guide each activity are also included. For example, MRE projects must pay particular attention to installing submarine cables or pipelines, the composition of the discharge plume, changes in the coastal-marine interface, intrusion in the territory of native peoples, and the execution of activities for citizen consultation.

The current legal framework allows for deploying infrastructure in the marine zone focused on oil exploitation, an industry with high environmental impact potential. In 2016, the CRE published the general requirements for submitting information on electricity generation projects; among that information, it is required to establish the type of generation (self-supply, cogeneration, import, export, independent power production and small production). The current process, applied to MRE, is discussed below, although the referred publication does not explicitly include it.

The first step is the technical information of the project, i.e., siting of MRE devices involves technological and market changes and adjustments to the national grid. MRE has an impact on the terrestrial and marine environment. In some cases, the devices are located offshore but require the transport of the energy produced and, therefore, the use of submarine cables, as well as licences for the establishment of microgrids or interconnection to the national grid (Cantarero et al., 2020; Ardelean and Minnebo, 2015)). In the case of introducing submarine cables, the oil sector is governed by the reference standards of PEMEX. Even though the marine area already has this type of infrastructure, the introduction of wires for the placement of MRE technologies is one of the elements with more studies needed to determine the possible environmental impacts (Taormina et al., 2018; Baring-Gould et al., 2016; Copping et al., 2020; Figueroa et al., 2022).

Returning to the potential environmental impacts, step two of the permit mentions incorporating their impact assessment. Here, it is necessary to consider specific elements of the study area and review the legal framework for mangroves and coral reefs and the dynamics and composition of the discharge plume in the cases of OTEC and SGE. A review of natural protected areas in the terrestrial and marine zones, endemic species, and seabed modifications is required for the five types of MRE.

In step four, corresponding to the social impact assessment, CRE requires identifying the presence of indigenous peoples and representative sites that should not be affected. In this section, it is essential to mention that the consultation process is not limited to asking for society's opinion. This is only one part of the assessment; the continuous work with the population provides information on the changes in the environment and supports introducing innovation in their environment.

The last step in the process is the presentation of the financial plan. As a new industry enters the energy market, financial programmes must

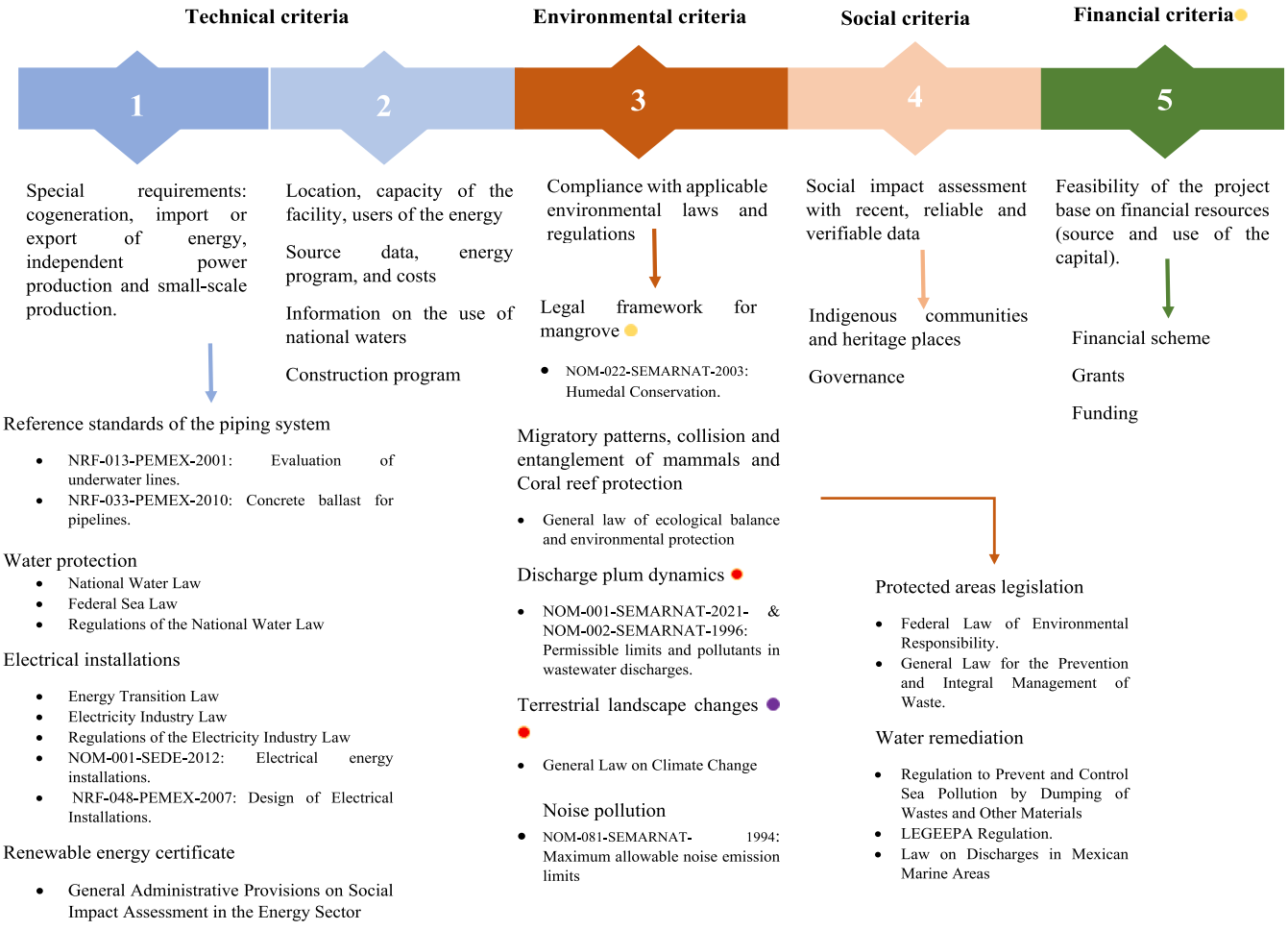

Fig. 3. Main regulatory aspects regarding MRE development plants.

be flexible in responding to the needs of a constantly changing market, in addition to the description of the financing mechanisms, regulatory tariffs and type of investment (Macdougall, 2016). This section integrates the application for renewable energy certificates issued by the country where MRE is introduced.

4. Discussion

In this study, we analyzed the renewable energy legal framework of Mexico to determine the requirements and obligations of the MRE projects and the feasibility of the development of the MEI. Mexico has a legal framework for RE, however, within the general permits is still necessary to determine the regulation for the commercial stage of RE. The energy market is focused on the use of fossil fuels due to subsidies and regulations. Despite the ratification of international treaties and agreements, local legal and regulatory measures are the prerequisites to transforming the energy market (Ghazali and Mustafa, 2020).

For this reason, MRE cannot reach the commercial stage, below are the laws that must be considered if the developers are in the process of device deployment. By commercial phase, we refer to the technologies that will be used to support the energy demand of coastal cities or isolated communities. We highlight the main barriers and pathways for project developers and stakeholders.

4.1. Infrastructure installation

Numerous structures, mainly for tourism purposes, have been installed in the coastal and marine zones worldwide, interacting with the environment and resulting in permanent modifications. Most human activities are concentrated on continental shelves (Lawrence and Fernandes, 2022). The coastal ecosystem is resilient enough for vast human activities; however, regulations are insufficient to manage industrial uses in the marine zone. The variety of economic activities on the Mexican coastline restricts the areas for the deployment of marine energy devices.

The installation, operation, maintenance, and risk assessment of offshore infrastructure involve complex tasks, and regulations of this nature are usually for the oil sector (Lin and Lu, 2023).

The arrangement directly depends on environmental conditions and the type of device. In the case of devices fixed to the seabed, such as turbines, the environmental impact assessment should include bathymetry, seabed morphology, and scour of the area of interest before positioning the turbines Barrow offshore wind, 2008), and their positioning can follow the stipulations for oil platforms or the technical guidelines of offshore wind turbines (Jiang, 2021).

The implications of turbine arrays require further research to allow technological progression, (Gauvin-Tremblay and Dumas, 2022) concluded turbines need specific guidelines for their array. This aspect is one of the most complex as in the installation process and operation the number of devices may be reduced.

In turn, to facilitate the development of the marine renewable energy industry, the regulations for testing should be more flexible than those for permanent deployment. In this context some countries have developed test sites such as Spain (https://www.bimep.com/en/bimep-area/technical-characteristics/) and UK (https://www.orkney.com/life/energy/emec).

4.2. Operation, maintenance, and local supply

In these project phases, the potential negative impacts are noise emission, species collision with the infrastructure, and discharge of substances. Barrow offshore wind, 2008), and their positioning can follow the stipulations for oil platforms (BOWind, 2008). Conducted post-construction monitoring for offshore wind farms in the Irish Sea, and the results indicate that noise emission from wind turbines is marginal. The report specifies that monitoring activities were conducted for three years during the construction phase, this included: a benthic and sediment contaminant survey, offshore transmission cable route, and bathymetry, among others.

Based on these studies, we recommended monitoring activities every year during the construction, operation, and maintenance stages, with the results the project developers will evaluate the periodicity of the monitoring in case of environmental impacts.

4.3. Spatial context and socio-cultural conflicts

The issues mentioned above illustrate the value of decision-maker involvement at different levels, such as government, state and private industry, and the population. In recent years, corporate social responsibility (CSR) has been promoted in the renewable energy sector seeking ecological and social sustainability, i.e., companies must regulate activities with consideration of environmental impacts and a human rights-based approach that ensures the environment of the population where the activities will be carried out (Strielkowski et al., 2021).

The MRE sector is responsible for conducting campaigns, workshops, and assemblies to communicate the project to be carried out. In these sessions, stakeholders are notified of the magnitude of the project, the site area, the potential impacts, and the benefits of marine energy development. Considering the SDGs, the ultimate aim of energy supply is to improve social welfare, either by supplying off-grid areas or by supporting specific local sectors such as desalination plants, hotels, and street lighting.

Since 2018 the social impact assessment has added to the requirements of energy projects; information is gathered on the population in the area of impact, industry, and the presence of indigenous peoples. During this phase, workshops, campaigns, and assemblies are designed and planned to gather the population and provide them with information about the project.

However, social dissatisfaction with a new sector is inevitable. It is, therefore, essential to develop the action plan in line with the social context in the intervention area. In addition to providing information on the social perspective, the citizen consultation process is an exploratory tool (Akita et al., 2020; Bailey et al., 2011; NSWGov, 2021) and, like the environmental impact assessment, the means of the social impact assessment increase the cost of the project.

4.3.1. General recommendations

Promote the use of RE becomes clear the need of political support that allows this energy resources to enter in the energy market, which is a competitive market led by fossil fuels.

As highlighted through this study, Mexico has a legal framework for renewable energy however there have been barriers to the diversification of the energy mix. Moreover, is an emerging economy with a wide diversity of ecosystem therefore the appropriate design of devices is required to minimize environmental impacts.

The acknowledgment of the potential of MRE allowed the conceptualization, design and development of devices from the different sources (SG, OTEC, wave, etc.) considering the characteristics of the Mexican coast, however, the energy transition will be achieved through government incentives. This needs an adequate legislation, determine capabilities and responsibilities of permitting authorities. Some key aspects to ensure MRI in the energy mix.

1. Incorporation of marine energy projects in the spatial planning and management of the study site.
2. Reduction of permit acceptance timeframes.
3. Coordination between permit-issuing institutions.
4. Permits for grid access and setting of tariffs.
5. Financial incentives and assistance for renewable energy: energy certificates or credits.
6. Consumer benefits for purchasing electricity of renewable sources.

This will enable stakeholders and investors to identify the risk, opportunities and potential return from the projects.

5. Conclusion

The objective of this study was to identify the regulatory elements that need to be considered for the establishment of MRE facilities on the Mexican coast. Undeniably, one of the current obstacles to the development of the MRE industry is the lack of coordination between levels of government, which has led to uncertainty in the permitting process. As a result, developers and investors continue to express the need for a clear and unambiguous regulatory framework. This weakens interest and prevents the rapid integration of MRE into the national energy mix. Another consequence of the unclear approval process is that the concepts are developed without any normative consideration, so there is a possibility that the final prototypes will not comply with the applicable laws. In this sense, this article has provided the existing applicable legal tools that developers and investors must consult in Mexico.

Specifically, the research focused on identifying non-technical challenges for MRE in Mexico. We found that a good opportunity for policy development is the separation of testing activities from commercial deployment. It is clear that the former is the temporary installation of unfinished products that can benefit from flexible regulations, while the latter is for permanent installations intended for commercial profit and must strictly comply with all current regulatory frameworks. We also found that most of the existing regulations concern the occupation of the marine area and the environmental impact, the weaknesses of the current documents are that no distinction is made regarding the location of the device (floating, fixed to the seabed or partially in the sea and inland) and the number of devices. The deployment of submarine cables is also given very little attention. In the case of salinity gradients and OTEC, sufficient regulations were found for discharges into water bodies, but there is a lack of standards for water extraction (i.e. permissible quality and quantities).

We recognise that the inclusion of the MRE industry is regulated differently in each country. The present research focuses on Mexico, but we hope that the review and needs expressed will be useful to investors and developers abroad. The present research on technologies, improving the environmental impact assessment and enhancing the social perception of MRE projects should lead to the construction of better practices in all energy sectors worldwide. However, the introduction of the MRE industry is not separate from local political positioning and the economic interests of local authorities. Scientifically, we can conclude that if the regulatory barrier is overcome, the population will soon benefit from clean and renewable energy.

In terms of environmental issues, marine areas can accommodate well-planned anthropogenic activities and impacts without losing connectivity and resilience. This means that the MRE regulatory framework must promote a sustainable industry based on good planning and management of available resources. In this context, another policy gap is

the determination of the allowable amount of energy to be extracted from the marine environment, which is beyond the scope of this study.

Electricity is part of people's livelihoods and in a scenario of rapidly increasing demand, countries need to provide it with a reasonable balance between access, quality and price to the end user. Modern electricity systems should be based on reliable and sustainable technologies and sources that reduce the carbon footprint of the electricity industry; MRE seems to be on the way to meeting all these requirements. At the same time, we must not forget that electricity generation is also a profitable business that drives national economic development, so its growth and development must be in line with the environmental and social constraints of each nation.

CRediT authorship contribution statement

G. Rivera: Writing – original draft, Methodology, Investigation, Conceptualization. **M. Ortiz:** Writing – original draft, Methodology, Investigation, Conceptualization. **E. Rivera-Arriaga:** Writing – review & editing, Investigation, Formal analysis. **E. Mendoza:** Formal analysis, Investigation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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