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Policy Issues and Options in Aquatic Food Systems

Review of Frameworks, Tools, and Studies

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Abstract

Although policies can be critical constraining or enabling factors for aquatic food systems (AqFS) development, scarce evaluation of the impacts of existing policies means that decision-makers have limited understanding of how to improve the design and implementation of effective policies. This paper reviews key policy issues in AqFS and how they have been analyzed and assessed to provide context-tailored policy options and guidance. Our review shows that countries face many policy issues but have little analysis on them. Despite the availability of a wide variety of frameworks, concepts, tools, methods, and approaches, their application in empirical analysis to solve policy issues in AqFS has been limited. More research is available on local- and community-level governance of fisheries, but less on national or subnational policies and regulations in AqFS. The few available policy studies focus on developed countries, with fewer applications in developing countries where growth of the aquaculture and fisheries sectors is much stronger. The studies provide useful policy options and guidance, and this review highlights the need for more such studies to address policy-related issues in the sector.

Keywords: policy analysis, aquatic food systems, aquaculture, fisheries, policy implementation, literature review

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1. Introduction

Global policymakers recognize the essential contribution of fisheries and aquaculture to global food security, nutrition, and economic growth, promoting sustainable expansion and intensification of the sectors through the "blue transformation" agenda (FAO, 2022a). A visionary strategy of the Food and Agriculture Organization of the United Nations (FAO), the blue transformation aims to enhance the role of aquatic food systems (AqFS) in feeding the world's growing population by providing the legal, policy, and technical frameworks required for sustainable growth and innovation of fisheries and aquaculture (FAO, 2022a).

Aquatic foods play an important role in global food systems, contributing to nutrition, food security, and employment (Arthur et al., 2022; Béné et al., 2016; Chan et al., 2019; E-Jahan, Ahmed, and Belton, 2010; Koehn et al., 2022; Nasr-Allah et al., 2020). In 2020, the primary fisheries and aquaculture sector employed about 58.5 million people, of whom 21 percent were women, mainly in the informal, low-paid and less-skilled segments of the sector (FAO, 2022a). Small-scale fisheries and aquaculture provided livelihoods for over 100 million people and sustenance for about 1 billion people, particularly in the global south (Short et al., 2021). Moreover, aquatic food supply chains played an important role in recovery from the COVID-19 pandemic (Belton et al., 2021).

The world's consumption of aquatic foods has increased significantly in recent years, and is projected to continue to rise (Costello et al., 2020; FAO, 2022a; Naylor, Hardy et al., 2021). A near doubling of global fish demand—due to growth in the global human population, incomes, and per capita consumption—is projected by midcentury assuming continued growth in aquaculture production and constant real prices for fish (Lam, 2016; Naylor, Kishore et al., 2021). Aquaculture has already surpassed capture fisheries production and will continue as the fastest-growing food subsector, with profound implications for global food security, income distribution, and ecological sustainability.

This increasing global demand puts pressure on the environment and on water-land ecosystems, their structure, and their functionality (Basurto and Nenadovic, 2012). Growing concerns over the environmental impacts have prompted a search for a governance framework that can guarantee aquaculture sustainability (Partelow et al., 2022). As the sector continues to grow and becomes more important for food security globally, there are calls for focusing on production of low-trophic-level species to reduce environmental impacts and increase sustainability, and for policy to support the responsible and sustainable use of feed ingredients for aquaculture production (Cottrell et al., 2020; Cottrell et al. 2021; Tacon et al., 2022). The concept of sustainability must include maintaining, renewing, or restoring, and the ethical trade-off between current economic pressures and the future needs of the environment (Wilkinson et al., 2001).

Fishery resources continue to decline because of overfishing, pollution, poor management, and other factors; thus, improving global fisheries governance and management remains crucial to restore ecosystems to a healthy and productive state and protect the long-term supply of aquatic foods (FAO, 2022a). The main challenge of regulatory and policy systems is to improve production and productivity in the fisheries and aquaculture sectors while reducing environmental impacts and ensuring social inclusion in the development process (Boyd et al., 2020; FAO, 2020, 2022a; Naylor, Hardy et al., 2021; Osmundsen et al., 2022).

The increasing emphasis on food systems has several development objectives:

- Economic (value chain competitiveness, improved incomes, and poverty reduction)
- Environmental (biodiversity, resilient ecosystems and environmentally sustainable)
- Social inclusion (equitable and fair, employment generation)

To support AqFS transformation, national policies should include the following:

- Economic policies—government initiatives to influence an economy through prices, taxation, interest rate, government funds, and so on
- Environmental policies—measures by the government for environmental protection and management in support of the public interest
- Social policies—measures by which societies meet human needs for security, education, work, health, and well-being

Governments and partners need to balance the trade-offs and guidance when developing such policies. Although policies can be critical constraining or enabling factors for AqFS development, the scarce evaluation of the impacts of existing policies give policymakers limited understanding of how to improve design and implementation of effective policies. The literature has little rigorous evidence assessing the effectiveness of aquaculture programs and few impact evaluation studies on aquaculture programs or policies (Gonzalez Parrao et al., 2021). Policy analysis and evaluation can close the gaps in data and evidence for informed decision making on policy programs and investments, and provide new insights in the design of appropriate policies to promote equitable and sustainable aquatic food systems.

Analyzing policies and having the appropriate management, regulation, and governance institutions and mechanisms are important to identify specific hindering and enabling conditions for expansion and intensification in aquaculture and fisheries (Anderson et al., 2019; Chan et al., 2019; Partelow et al., 2022; Peel and Lloyd, 2008; Subasinghe et al., 2009). Moreover, achieving sustainable development of fisheries and aquaculture requires commitment from government, the private sector, and civil society (FAO, 2022a; Muringai et al., 2022; Ragasa et al., 2022). Many national policies now recognize the importance of fisheries and aquaculture in food and nutrition security and sustainable development (FAO, 2020, 2022a; Farmery et al., 2021; Koehn et al., 2022). Nevertheless, fisheries and aquaculture require more policy research. In order to develop more targeted and systematic policies and address the global challenges of equity, nutrition, and sustainability, that research needs to examine more closely the diversity of AqFS and impacts on the well-being of poor and vulnerable social groups (Anderson et al., 2019; Simmance et al., 2022). For example, a recent study that analyzed national policy documents of 194 countries reveals a frequent failure of policies to address political and gender-based barriers to social justice in AqFS outcomes (Hicks et al., 2022). Box 1 sets out the numerous policy issues and questions that countries, sector planners, and decision-makers are asking—or should be asking.

Box 1. Illustrative examples of AqFS policy issues and questions

- **Fish seed policies**
  - Should the country allow foreign fish strains?
  - What are the productivity differentials between the latest generations of genetically improved fish strains and the local strains? What are the social, economic, and environmental costs and benefits of the genetically improved strains versus local strains?
  - How can local breeding capacity be strengthened (versus importing highly productive strains from other countries)?
- **Market and trade policies**
  - Are import bans effective in boosting local production or detrimental in terms of higher food prices and reduced domestic food security?
  - How can we improve competitiveness of local fish production?
  - What bilateral or regional trade arrangements can be negotiated and adopted to promote fish and feed production and promote aquaculture trade within regional blocks?
  - How do we best design and enforce fish disease monitoring and surveillance within and across borders?
  - How do we set up a one-stop shop for business transactions?
  - What credit market policies and innovations can solve credit access issues and credit market failures?
- **Subsidy programs**
  - Are subsidies effective? What are the optimal amount and type of subsidy?
  - What is the best way to support the aquaculture and fisheries sector without creating too much dependence on aid/subsidy?
- **Fiscal policies**
  - How can we incentivize and facilitate private sector investments?
  - How can we encourage more fish value addition and processing?
  - What are the effects of foreign currency fluctuations and fiscal policies on AqFS?
- **Environmental, biosecurity, and food safety policies**
  - Will mandatory certification effectively improve fingerling quality and fish production?
  - How can we better enforce environmental policies and regulations in AqFS?
  - How can farmers adapt to a more extreme climate, and what strategies can the government use to support climate resilience?
  - What are optimal zoning strategies, and how do we address land/water tenure issues?
  - Which quality assurance approaches are more effective: mandatory certification versus voluntary certification, and facility inspection versus end-of-product testing?
  - Are education and awareness raising more effective than regulation?
- **Social policies**
  - How can we encourage more women and youth into aquaculture and fisheries value chains?
  - How can we challenge gender norms and empower women to be active producers and entrepreneurs in aquaculture and fisheries value chains?
- **Nutrition policies**
  - How can we better diversify farmed fish species to contribute to food and nutrition security?
- **Policy and political processes**
  - How do we change policy? Who are the decision-makers/champions, and how do we influence them? How do we increase policy attention, public expenditure, and investments in AqFS?
- **Development policies**
  - How can policy support the development of more sustainable technological advances in AqFS such as integrated multitrophic aquaculture, multiuse platforms at sea, and so on?
  - How can policy support the development of effective governance solutions for sustainability of AqFS?

The link between AqFS research, policies, and stakeholders is important for sustainable development in fisheries and aquaculture (Aberman et al., 2009; Krause et al., 2015). Some argue, however, that a disconnect exists between science, people, and policy, and that the social and economic implications of aquaculture development take a back seat to trade, ecological, and technological motivations amid efforts toward sustainable intensification of aquaculture production (Krause et al., 2015). Many countries lack the participation and consideration of a wider range of stakeholders in decision-making and policy-formulating processes surrounding aquaculture implementation (Krause et al., 2015). To be effective and inclusive, decision-making and policy-formulating processes should be informed by science where relevant, and include stakeholders at various levels of decision-making. For example, aquaculture policies and regulations have so far been primarily influenced by traditional fisheries managers, environmental groups, and natural scientists (Anderson et al., 2019).

Analysts, researchers, and policymakers require the necessary frameworks, tools, and methods for policy analysis to guide them in evaluating different policy alternatives or assessing the impact of policy changes. A better understanding of national policymaking processes is crucial to inform policy decisions, influence policy change, analyze the feasibility of policy alternatives, and improve policy outcomes (Oliver and Cairney, 2019; Resnick et al., 2015). Linking research and policy is also necessary to provide evidence for policymaking and improve the impact of policy on the poor and other vulnerable groups (Start and Hovland, 2004).

This paper presents an extensive review of the different frameworks (or concepts), tools, methods, and approaches available in the literature for policy analysis in the fisheries and aquaculture sectors. It focuses on studies applying the policy analysis frameworks/tools/methods to fisheries and aquaculture in developed or developing countries, as well as some frameworks/tools/methods applied to other sectors but relevant for studying policies in aquaculture and fisheries. The paper provides examples of studies that used each framework/tool/method, how it was used, and the data requirements. It separates, where possible, the studies on aquaculture and fisheries. This review fills a gap in the literature by providing a systematic overview of frameworks, tools, and approaches for policy analysis in the fisheries and aquaculture sphere. It lays out for researchers, scientists, practitioners, policymakers, civil society, and others the valuable frameworks, concepts, tools, and methods that help support their activities.

The next sections are structured as follows. Section 2 presents a brief description of the literature search methodology, followed by a description of the major frameworks and concepts identified in the literature on policy analysis and evaluation in AqFS research (section 3). Section 4 provides an inventory and description of the different tools, methods, and approaches used for policy analysis and evaluation that have also been identified in the literature. Section 5 discusses policy issues, solutions, and lessons from the literature on policy analysis and evaluation, and other policy-related studies in AqFS. Last, the conclusion considers the implications for policy analysis and development in AqFS.

2. Literature search methodology

The scholarly articles for the literature review come from the web databases of Google Scholar, ScienceDirect, and Semantic Scholar, which include peer-reviewed online academic journals and books, conference papers, theses and dissertations, preprints, abstracts, technical reports, and other scholarly literature. The literature search did not capture unpublished or gray literature unavailable online or articles not written in English.

The search for scholarly articles used a combination of the keywords "policy," "policy analysis," "policy analysis + aquaculture," and "policy analysis + fisheries" to identify articles with such keywords in the title or abstract or as a subject within the articles. The search was expanded using the keywords "law," "regulation," and "governance" in order to capture governance issues in aquaculture and fisheries. Box 2 defines in more detail the keywords used in the search, together with other terminologies used in this paper. The global search returned more than 400 scholarly articles.

Box 2. Definitions of key search words and terminologies

Policy: A law, regulation, procedure, administrative action, incentive, or voluntary practice of governments and other institutions (Boyd-Brown et al., 2022). Several types of policy operate at different levels (national, state, local, or organizational): (1) *legislative policies* are laws or ordinances created by elected representatives; (2) *regulatory policies* include rules, guidelines, principles, or methods created by government agencies with regulatory authority for products or services; and (3) *organizational policies* include rules or practices established within an agency or organization. This paper defines policies as broad statements on development objectives, often in policy and strategy documents at the national and subnational levels.

Policy analysis: The systematic, analytic, and ethically informed comparison and evaluation of policy alternatives available to public actors for solving social problems (Weimer and Vining, 2017). Policy analysis is designed to supply information about complex problems and to assess the processes by which a policy is formulated and implemented in order to address those problems, through evaluating the policy's anticipated outcomes or actual results (Yanow, 2000).

Policy analysis methods: Systematic procedures for attacking specific problems with specific purposes, using basic or researched methods (Patton et al., 2013). *Basic methods* are quickly applied but theoretically sound ways to aid in making good policy decisions. *Researched methods* (e.g., survey research, model building, and input-output studies) are well codified with routine steps of exploration and accepted standards of scientific behavior and may require substantial budget, time, and data to achieve results (Patton et al., 2013).

Policy evaluation: Applies evaluation principles and methods to examine the content, implementation, or impact of a policy (Hanberger, 2001). Policy evaluation uses a range of research methods to systematically investigate the effectiveness of policy interventions, implementation, and processes, and to determine their merit, worth, or value in terms of improving the social and economic conditions of different stakeholders (Vedung, 2017).

Social policy: A deliberate intervention by the state to redistribute resources among its citizens so as to achieve a welfare objective (Baldock et al., 2011). A social policy is always a proactive attempt to change a given social order, with the classic justification that it will lead to greater social justice, though that may not be the classic outcome (Baldock et al., 2011).

Economic policy: A wide range of measures used by governments to manage the economy and achieve various objectives: improving the population's standard of living, alleviating poverty, promoting sustainable growth, achieving full employment, maintaining price stability, and reaching a fair distribution of income among others (Bénassy-Quéré and Pisani-Ferry, 2018).

Environmental policy: Primarily concerned with governing the relationship between humans and the natural environment in a mutually beneficial manner, and traditionally defined in terms of the problems it addressed, such as controlling pollution and waste flows, and limiting habitat loss (Benson and Jordan, 2015). Governance arrangements are also sought for environmental problems that require cooperation, for example, through behavior change or adoption of certain practices, and environmental governance offers a framework that specifically seeks positive social-ecological outcomes (Cocklin and Moon, 2020).

Framework: A suggested point of view for addressing a scientific problem. Although it often suggests testable hypotheses, it is not a detailed hypothesis or set of hypotheses (Crick and Koch, 2003). A good framework sounds reasonably plausible relative to available scientific data and turns out to be largely correct. Although unlikely correct in all the details, it—unavoidably—often contains unstated (and often unrecognized) assumptions (Crick and Koch, 2003).

Governance: The rules, structures, processes, and behavior that affect how powers are exercised, particularly as regards openness, participation, accountability, effectiveness, and coherence (Gray, 2006). It involves the creation of institutions, rules, and organizations, and the selection of normative principles to guide problem solving and institution building (Huitema et al., 2016). Good governance has seven principles: legitimacy, transparency, accountability, inclusiveness, fairness, connectivity, and resilience (Aguado et al., 2021). Governance theory distinguishes between three ideal modes of governance: (1) *hierarchical governance* reflects interactions between a government and its citizens (a top-down style of intervention), and expresses itself in policies and in law; (2) *self-governance* in modern society has actors take care of themselves, outside the purview of government; and (3) *co-governance* has societal parties join hands with a common purpose in mind and stake their identity and autonomy in the process (Kooiman et al., 2005). This paper defines governance to include structures and processes, rules, institutions, and organizations, usually at a lower level, that support or constrain the implementation of the broader national or subnational policies.

Screening of the articles occurred in steps. First, all titles and abstracts were screened, keeping articles linked to policy analysis and/or aquaculture and/or fisheries. Second, all articles without full text accessible online were excluded. Third, the results were refined by screening the full text of articles to evaluate the content. Fourth, articles without relevant information were excluded, leaving a total of 306 articles in the final database. Fifth, a review was conducted using the full text of the articles that provided the relevant information. The bibliographic data on the reviewed articles were imported and managed using Zotero reference management software. Results from the review exercise are reported using a narrative synthesis.

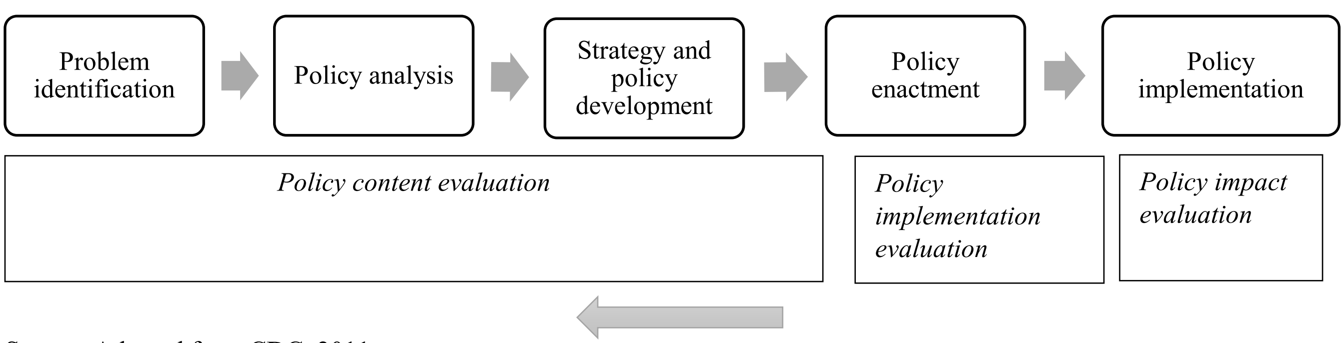
3. Frameworks and concepts for policy analysis and evaluation

3.1. A general framework for conducting policy analysis and evaluation

Policy analysis and policy evaluation both aim to provide policymakers with information to help them make better decisions. It is a learning process that helps policy makers to get a better understanding of policy problems and potential solutions in order to design and implement appropriate policies. As already defined, *policy analysis* primarily aims to identify policy options or alternatives for addressing a specified problem given a pending decision. It can be conducted ex ante to anticipate the results of alternative policies in order to choose among them, or ex post to describe the consequences of a policy (Patton et al., 2013). The basic policy analysis process includes problem definition, determination of evaluation criteria, identification of alternatives, evaluation of alternatives, comparison of alternatives, and assessment of outcomes (Patton et al., 2013).

Policy evaluation, which focuses on existing policy, is an integral part of each step in the policy process (Hanberger, 2001). Evaluating the development of a policy helps in understanding the policy process, its context, content, implementation, and outcome (Brownson et al., 2009). The type of policy evaluation selected depends on many factors, and often more than one type of evaluation is needed. Each type of policy evaluation can provide valuable information for the planning and interpretation of other types of evaluation and the consequences. Figure 1 illustrates the relationship between the main stages of the policy process and three types of policy evaluation.

Figure 1. The policy process and types of policy evaluation

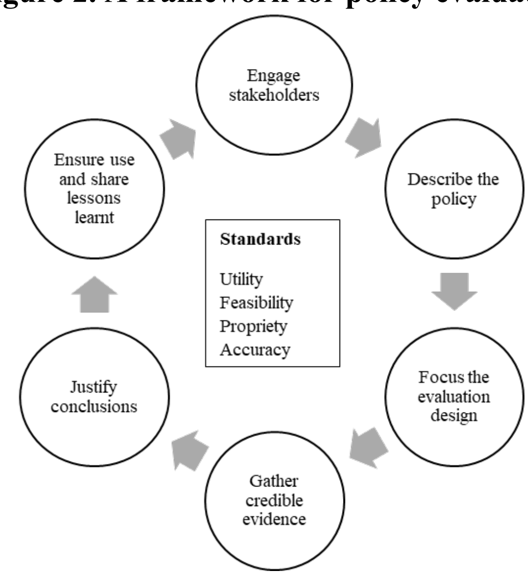


Source: Adapted from CDC, 2011

The policy process begins with problem identification and ends with policy implementation, and often a feedback loop leads back to the policy problem identified. Each type of policy evaluation focuses on a different phase of the policy process. *Policy content evaluation* examines whether the content clearly articulates the goals of the policy, its implementation, and the underlying logic for why the policy will produce intended change. *Policy implementation evaluation* examines whether the policy was implemented as intended and is a critical component in understanding the effectiveness of the policy. It can provide important information about the barriers to and facilitators of implementation and a comparison between different components or intensities of implementation *Policy impact evaluation* examines whether the policy produced the intended outcomes (short-term and intermediate) and impact.

Figure 2 presents a general framework for conducting policy evaluation. The framework proposes six interconnected steps to guide researchers in conducting a policy evaluation in practice, with recommended standards that can provide sound guidelines.

Figure 2. A framework for policy evaluation



Source: Adapted from Milstein et al. (2000).

The six steps may or may not occur in a nonlinear sequence: (1) *engage stakeholders*, that is, the primary intended users and those involved or affected by the policy; (2) *describe the policy*, including its needs, expectations, activities, resources, stage of development, and context, and the logic model that displays how the entire policy is supposed to work; (3) *focus the evaluation design* by describing the purpose, users, uses, questions, methods, agreements that summarize roles, responsibilities, budgets, and deliverables of the policy evaluation; (4) *gather credible evidence* with clearly defined indicators, sources, quantity and quality of information, and logistics used to gather and handle evidence; (5) *justify conclusions*, involves appreciation of stakeholders' standards, analysis/synthesis to determine the findings, interpretation of findings, judgment of how the findings should be valued according to the selected standards, and recommendations; and (6) *ensure use and share lessons learned*—that is, design the evaluation to achieve intended uses, prepare stakeholders for eventual use, provide continuous feedback to stakeholders, follow up with intended users to facilitate the transfer of conclusions into appropriate actions or decisions, and disseminate lessons learned to relevant stakeholders or those interested in the policy.

For effective policy evaluation, the following standards should be considered: (1) *utility standards* ensure that information needs of intended users are satisfied (for example through stakeholder identification, evaluator credibility, information scope and selection, values identification, report clarity, report timeliness and dissemination, and evaluation impact); (2) *feasibility standards* ensure viable and pragmatic policy evaluation (practical procedures, political viability, and cost effectiveness); (3) *propriety standards* ensure that the policy evaluation is legal and ethical, with due regard for the welfare of those affected (service orientation, formal agreements, rights of human subjects, human interactions, complete and fair assessment, disclosure of findings, conflict of interest, and fiscal responsibility); and (4) *accuracy standards* ensure that the policy evaluation produces findings that are considered correct by revealing and conveying technically accurate information (defensible information sources; valid, reliable, and systematic information; analysis of quantitative and qualitative information; justified conclusions; impartial reporting; and meta-evaluation).

3.2. Frameworks and concepts for AqFS policy analysis and evaluation

Effective policy analysis and evaluation require approaching a problem from various perspectives, integrating quantitative and qualitative information, and using appropriate tools or methods to test the feasibility of proposed policy alternatives (Patton et al., 2013). This section describes the frameworks and concepts available for studying policy and governance problems in AqFS. Annex 1 presents a summary table of different frameworks that have been applied in the AqFS literature.

3.2.1. The kaleidoscope model of policy change

The *kaleidoscope model* has been applied to study the policy issues and drivers of policy change in agriculture and food and nutrition security across diverse countries, stakeholders, and decision-making environments (Resnick et al., 2015). The model identifies key variables that explain what policies emerge on a government's agenda, how they are designed, whether they are adopted and implemented, and how and why they might be refined. It draws on actual episodes of policy change in developing countries from the agricultural and nutrition sectors as well as other domains. Empirically validated through country case studies in a wide range of policy domains, the model gives a framework for policymakers, donors, and other stakeholders interested in better understanding whether, why, and how specific policies are implemented.

In identifying key variables that help drive policy change, it takes into account the collective action of actors, the institutions that provide the context for that action, and how policies change over time. It builds on insights from interactive models while recognizing that interests, institutions, and ideas have relevance to the policy process at different times. It enables the understanding of why a policy change occurs in one country, in one policy arena, or at one time period but not another. The model can be used to identify whether a policy is actually implemented, and it gives scope for analyzing why change does not occur. In practice, it allows for tracing why a policy fails to be implemented by taking into account where gaps may have existed during other stages of the policy cycle. At any particular time, some factors—such as the influences and actions of national policymakers—may have a larger role than others in influencing policy change.

The kaleidoscope model differentiates between primary and secondary variables relevant for influencing each stage of the policy process. Primary variables, the "key determinants of policy change," are in turn influenced by secondary variables, or "contextual conditions." The model identifies five key elements of the policy cycle: (1) agenda setting, which depends on the focusing events, powerful advocacy coalitions, and the relevant policy problem; (2) policy design, influenced by pressing versus chosen problems, ideas and beliefs, and cost-benefit calculations; (3) policy adoption, driven by veto players, relative power of proponents versus opponents, and propitious timing; (4) policy implementation, influenced by institutional capacity, budgetary allocations, and the commitment of policy champions; and (5) policy evaluation and reform, which depend on changing beliefs of veto players and champions, and available resources relative to costs.

The policy process is often iterative and nonlinear because past decisions influence future policies. Most existing theories on policy process and change focus implicitly on one or more of the key elements. Focusing on a particular stage of the policy process reveals a different constellation of key variables. The kaleidoscope model has been applied empirically to analyze agricultural inputs policies such as Agricultural Input Subsidy Reform in Africa (Resnick et al., 2017), Ghana's Fertilizer Subsidy Program from 2008 to 2015 (Resnick and Mather, 2016), micronutrient policy in South Africa (Hendriks et al., 2016), Tanzania's Fertilizer Subsidy Programs from 2003 to 2016 (Mather and Ndyetabula, 2016), and micronutrient policy change in Zambia (Haggblade et al., 2016). Although not yet applied to AqFS, this model has great potential for use in understanding aquatic food system policies in different contexts, and identifying the determinants of policy change in order to improve the policy process and support better policy design and implementation.

3.2.2. Aquaculture governance framework: The commons perspective

Partelow et al. (2022) developed a conceptual framework based on a shared resource or commons perspective which is important for identifying the social and environmental commons creating collective action problems or social dilemmas for aquaculture governance. This framework offers a tool for identifying and analyzing existing shared resources in aquaculture. It draws on several theories—such as the common-pool resource, public goods theory, institutional theories, and analysis—and their applications in aquaculture systems. It helps conceptualize the origin of governance problems and the analysis of institutional interactions and solutions. In addition, it provides theoretical explanations for the origins of governance problems unique to aquaculture and acts as an analytical tool for case studies.

The framework categorizes governance problems as first- and second-order collective action problems. *Collective action problems* arise in governing shared resources because typical individual-use strategies (maximization, free riding) often diverge from group or collective interests (fair contributions, sustainable use). The two types of collective action problems in aquaculture are (1) *first-order aquaculture commons*, linked to direct use and provision, with governance challenges that include water quality, water quantity, physical space, inputs, genetic diversity, mitigating infectious disease, earth and climate stability, infrastructure, knowledge, and money; and (2) *second-order institutions*, for provision, maintenance, and adaptation of institutions to govern the use of first-order commons. These institutions include the rules and norm systems that structure property rights and markets, to better align individual behavior and collective interests through governance. Institutions guide human behavior and largely influence the sustainability of the appropriation and provision of shared resources or commons, helping to solve the first-order collective action problem of tangible resources.

The framework identifies two overarching types of institutions, rule systems and norm systems, as the basis for understanding institutions, such as property rights and markets. *Rule systems* and governance structures are critically important social public goods. Formal rules typically refer to written rules, often formally enforced; operational rules are the practical day-to-day rules providing a set of options for aquaculture stakeholders to make actionable choices. *Norm systems* are also public goods in the form of social and cultural practices, or conventions making up a good proportion of a community's social capital. Markets are bundles of rules and norms or institutional combinations. Property rights refer to who has access, withdrawal, management, exclusion, and alienation rights to shared resources. Property rights and markets, as structured by rules and norms, exist in many forms to solve first-order collective action problems.

Governance challenges are categorized into environmental and social commons. *Environmental commons* are first-order collective action problems in the governance of common pool resources—for example, fresh water quantity and availability, water quality, physical space, and public goods such as genetic diversity, earth system and climate stability, mitigating infectious diseases, and inputs (seed stock and feed inputs, plant seedlings, animal eggs or juveniles, and so on). *Social commons* include public and private goods that often have interrelated governance and collective action problems, and that exist together in bundles such as knowledge, public infrastructure, and money or financing. Social commons consist of both first- and second-order collective action problems, bundled together.

A checklist of steps for applying the framework include: (1) identify the relevant commons; (2) analyze the role of institutions; (3) identify the property rights and markets shaping the use or provision of the relevant commons; (4) through literature review or empirical research, determine the rules and norms involved; and (5) consider further questions such as how the commons and institutions interrelate to each other, how they have evolved over time, and whether institutions match issues and challenges in relation to the relevant commons or if significant institutional gaps exist. Analysis can be conducted at the local or country level, or at a multicountry level if the shared commons involve cross-border interactions and governance. Identifying the commons and institutions at different levels can be combined with other theories beyond commons and collective action theories, such as multilevel governance theory, network governance, or polycentricity to further unpack governance interactions.

In order to apply the framework in analyzing aquaculture governance, four key points are important: (1) cross-sector links between capture fisheries, agriculture, public health and nutrition, and so on; (2) land–water–sea connectivity issues; (3) recognition of governance's broad and pluralistic nature, and understanding it as an embedded feature of social systems; and (4) recognition that external and generalized governing strategies (e.g., policies, legislation, property rights configurations, market mechanisms) will not likely be successful unless they are evolved within or tailored to the local context. Partelow et al. (2022) applied the framework to four case study countries to identify existing aquaculture commons, institutions, and governance challenges in recirculating aquaculture systems (Denmark), raceway flow-through systems (Nepal), mariculture (Peru), and earthen ponds (Philippines). The framework was used to characterize the context and use of specific shared resources, institutional configurations, governance challenges, and potential solutions.

Several studies have investigated issues surrounding aquaculture governance in other contexts such as: governance of aquaculture value chains in Asia (Ponte et al., 2014), aquaculture policy and regulation for the development of integrated multitrophic aquaculture in Europe (K. A. Alexander et al., 2015), challenges for policymakers in governance of multiuse platforms at sea for energy production and aquaculture in European seas (Stuiver et al., 2016), and governance and planning policy in the marine environment for regulating aquaculture in Scotland (Peel and Lloyd, 2008).

3.2.3. Fisheries governance frameworks

According to Basurto and Nenadovic (2012), policies for fisheries governance include three broad groups of policy instruments deployed either individually or in combination to achieve a desired management objective, depending on the context. *Output or catch controls*—such as total allowable catch, catch quotas, and vessel catch limits—regulate the catches of a fishing fleet or individual fishers or boats. *Input or effort controls*—consisting of limited licenses, effort quotas, and gear and vessel restrictions—limit the number of fishers or boats in the fishery and regulate the type of fishing gear and the length of its use. *Technical measures*—such as time and area closures and size and sex selectivity through gear regulation—restrict the catch that can be achieved for a given amount of effort.

The literature identifies three main frameworks for analyzing fisheries governance. First, the *social-ecological systems framework* provides guidance on assessing the social and ecological dimensions that contribute to sustainable resource use and management (Leslie et al., 2015). Binder et al. (2013) and Partelow (2018) provide a detailed review of the social-ecological systems framework, its applications, methods, modifications, and challenges. Some applications include sustainability assessment of fisheries in Chile and Mexico (Basurto et al., 2013; Leslie et al., 2015); linking fisher perceptions to social-ecological context in Costa Rica (Partelow et al., 2021); improving pond aquaculture production in Lombok, Indonesia (Senff et al., 2018); and analyzing the relationship between people and policy in aquaculture development (Krause et al., 2015).

Second, the *interactive governance and governability framework* has been used in various contexts (Bavinck et al., 2013; Jentoft and Bavinck, 2014; Jentoft and Chuenpagdee, 2015; Kooiman, 2016). According to Kooiman (2016), interactive governance includes the whole range of interactions to solve societal problems and create societal opportunities, the formulation and application of principles guiding those interactions, and the care for institutions enabling them. Governability is the overall quality for governance of any societal entity, divided into a system to be governed, a governing system, and a system of interactions mediating between the two. Diversity, complexity, dynamics, and scale are identified as the major variables influencing governance and governability of societal entities.

Third, *participatory fisheries governance* approaches emphasize democratic engagement and deliberative processes steering the complex set of interactions among stakeholders with different needs, demands, and interests, and whose activities are often managed by multiple agencies and regulations (Aguado et al., 2021). Participatory approaches have been used to analyze the quality of fisheries governance in Spain using a multicriteria framework (Aguado et al., 2021); fisheries governance in Europe (Pita et al., 2012); how regional advisory councils can incorporate stakeholder knowledge into fisheries governance (Linke et al., 2011); rights-based fisheries governance (Allison et al., 2012); participation, integration, and institutional reform in fisheries governance (Linke et al., 2020); and community empowerment through participatory fisheries research (Wiber et al., 2009).

3.2.4. Institutional analysis and development framework

The *institutional analysis and development* (IAD) framework considers institutional design and performance in the management of common pool resource systems such as fisheries (Ostrom, 2011, 2007b). One of many approaches to conducting institutional analysis, the IAD framework offers a systematic approach to analyzing the elements, links, and underlying logic of policy designs, and is an integrative approach for deconstructing and reconstructing policy designs (Carter et al., 2016). It has been used extensively to design policy experiments and empirically test theories and models linking ecological-economic systems, institutions, and the sustainability of common pool resource systems (Rudd, 2004). The IAD framework has been used for empirical analysis of fisheries management institutions in both developed and developing countries (Imperial and Yandle, 2005).

Institutional analysis examines the problems that individuals (or organizations) face and how rules address the problems (Ostrom, 1990). As noted earlier, fisheries management presents a classic collective action problem, with common problems such as poor incentive structures, inefficient fishing practices, or those inconsistent with community values (Olson, 1971; Ostrom, 1990).

Four competing institutional arrangements exist for fisheries management, according to Imperial and Yandle (2005): (1) *bureaucracy*—the ''leviathan'' or centralized bureaucratic arrangement based on government regulation; (2) *markets*—market-based arrangements that allocate total allowable catch using individual transferable quotas; (3) *community*—community-based arrangements that rely on self-regulation of fisheries by communities and user groups; and (4) *co-management*—an arrangement that relies on shared management between government agencies and user groups. Because different institutional arrangements can achieve the same policy objective, policy analysis needs to consider the comparative advantage of an institutional arrangement, given contextual factors and competing goals and values of decision-makers, in order to provide policy-relevant information and advice to decision-makers. In fisheries, this advice often centers on the nature of the rules used to alter fisher behavior and maintain sustainable fish stocks. Thus, IAD focuses on such things as the organization of the fishery (e.g., location, community characteristics, industry structure), who makes decisions and how, the rules used to allocate and distribute resources, rules governing fisher behavior, and rule enforcement.

According to Imperial and Yandle (2005), three major elements of the IAD framework are used to analyze fisheries management institutions. First, the contextual setting—which typically includes a fishery and the community affected by the rules governing the fishery—focuses on three sets of contextual factors: the physical setting, attributes of the community, and the existing institutional setting (Ostrom, 2007). Second, transaction costs associated with developing and implementing fisheries policy include information costs, coordination costs, and strategic costs (Ostrom et al., 1993). Third, the assessment of overall institutional performance relies on four interrelated criteria to assess the overall performance of institutional arrangements: efficiency, equity, accountability, and adaptability (Ostrom et al., 1993). It is also important to understand the relationship between institutional performance and policy outcomes. The ideal situation is to have well-performing institutional arrangements with sufficient underlying restrictions on fishing behavior to maintain sustainable fish stocks (Imperial and Yandle, 2005). The multiple and competing policy objectives in fisheries management necessitate the use of various criteria to assess overall institutional performance and to understand the trade-offs that exist between them.

The IAD framework has been applied in some empirical aquaculture studies to understand the challenges in analyzing governance of coastal and marine ecosystem services in Qingdao, China (Li et al., 2016); developing environmentally sustainable cage culture farming in Lake Maninjau, Indonesia (Yuniarti et al., 2021); analysis of aquaculture in Galicia, Spain (Fernández-González et al., 2020); and assessing policy design and interpretation of aquaculture policies in Florida and Virginia of the United States (Siddiki, 2015).

3.2.5. Systems thinking

Systems thinking provides a methodology for better understanding the nonlinear behavior of complex systems and improving assessment of the consequences of policy interventions (Hynes et al., 2020). It can complement established approaches to policy analysis and implementation by providing greater insight into the complex, dynamic systems of the modern world (Hynes et al., 2020). The methodology and tools of systems thinking can respond to the concerns and priorities of governments by providing valuable insights into policy choices, trade-offs, and synergies; improving the effectiveness of policy interventions; and facilitating the assessment and management of risk (Hynes et al., 2020). Based on the belief that components of a system will act differently when viewed in isolation from other parts of the same system, the approach sets out to view whole structures in a holistic manner (Stead, 2019).

According to Hynes et al. (2020), the application of systems thinking includes five practical tools: (1) *economic analysis* uses systems analysis models that can integrate real-world dynamics and complex collective decision-making, and facilitate the evaluation of policies' effectiveness and impacts; (2) *impact assessments* link to the environment and sustainable development; (3) *system mapping* decomposes the behavior of a complex system into subprocesses that can be described in a relatively simple way to give policymakers a broad view of the drivers of policy outcomes; (4) *network theory* and *agent-based modeling* quantitatively measure, model, and manage systemic risk and resilience to give policymakers an effective and efficient resilience management framework; and (5) *food systems thinking* is commonly used for understanding and responding to nutrition, food security, and sustainability challenges by integrating the social, economic, environmental, and health aspects of food from production to consumption (Simmance et al., 2022).

Food systems thinking goes beyond value chain approaches by recognizing the multidirectional relations between production and consumption practices, with outcomes that extend beyond producer performance. It includes food security or sustainability, broader societal transitions such as urbanization and globalization, and their influence on where and how food is produced, distributed, and consumed (Tezzo et al., 2021). A framework based on food systems thinking captures the ways complex drivers of change at a broader scale affect the functioning of food systems, often with uncertainty and unforeseen consequences that feed back into the system, implying a link between resilience of food systems and food security (Béné, 2020). With respect to the concept and challenges of food systems, Simmance et al. (2022) identify three broad priority areas for fisheries, aquaculture, and AqFS research: (1) examine a broader set of aquatic food types amid diverse diets, (2) examine systemwide flows (and losses) of nutrients and trade-offs among objectives, and (3) focus on opportunities and innovations to address nutritional needs of vulnerable and marginalized social groups.

The High-Level Panel of Experts on Food Security and Nutrition present food systems thinking (Clapp et al., 2020; FAO, 2018; HLPE, 2017) as an ambitious framework for researchers and policymakers to shape research design, data interpretation, policy, investment, and action. Adopting the framework can potentially improve research and policy understanding of drivers of change and their impacts across all stages of food systems, from food production to health and nutrition outcomes, and as such can help determine how various investment, action, or policy adjustments might affect sustainability, equity, and food and nutrition security. The comprehensive food systems framework (HLPE 2017); Simmance et al., 2022) comprises diverse components and relationships with social, economic, environmental, health, and nutrition impacts: (1) food supply chains (production systems, storage and distribution, processing and packaging, retail and markets); (2) food environments (food availability and physical access, economic access, promotion, advertising and information, food quality and safety); (3) consumer behavior and diets (quantity, quality, diversity, safety); and (4) drivers of food systems (environmental, technological, political and economic, social-cultural, demographic, institutional), which act upon the entire system or parts of the system. Food systems thinking has been adapted and used to study issues in aquaculture and fisheries. For example, Tezzo et al. (2021) conducted a systematic literature review to analyze development research and policies that have accompanied the ongoing transition from freshwater capture fisheries to aquaculture in South and Southeast Asia using a food fish systems framework.

Other empirical applications of the systems thinking in general to fisheries and aquaculture include Brunton et al. (2019), who used systems thinking to understand the contribution of aquaculture to antibiotic resistance in Vietnam. Desbois et al. (2021) used systems thinking to identify and assess the feasibility of potential interventions to reduce antibiotic use in tilapia farming in Egypt. Tiller et al. (2014) used systems thinking to assess stakeholder adaptive capacity to salmon aquaculture policies in Norway. Other studies have used systems thinking to examine marine fisheries management systems in China (Su et al., 2022), South Africa (Sowman, 2011), and the United States (McGuire and Harris, 2011); the impact of Europe's coastal fisheries policy (Symes et al., 2015); and social-ecological links that can inform a transition toward sustainability in small-scale fisheries (Kittinger et al., 2013).

4. Overview of tools, methods, and approaches for policy analysis and evaluation in AqFS

Numerous studies in the literature have employed or discussed different tools, methods, or approaches for policy analysis with empirical applications in aquaculture and fisheries, and in other disciplines. A range of research tools, methods, and approaches—grouped into the following categories—can be used to systematically investigate the content of policies, implementation, and processes, or the effectiveness of policy interventions (see Annex 2 for a summary table).

4.1. Tools for ex ante assessment of policy options

The following tools, methods, or approaches can be employed for choosing among policy options or to substantively contribute to a proposed policy before implementation.

4.1.1. Multicriteria decision analysis

Multicriteria decision analysis (MCDA) encompasses the techniques and situations in which two or more objectives or criteria are to be considered for a given decision. MCDA provides a methodology that enhances effective decision-making by providing for both logical, systematic analysis and imaginative creativity (Howard, 1980). The procedure permits representing the decision-maker's information and preferences concerning the uncertain, complex, and dynamic features of the decision problem into an understandable framework to facilitate decision-making (Huang et al., 2011; Liu, 2007).

MCDA is used to discover and quantify decision-maker and stakeholder considerations about various (mostly) nonmonetary factors in order to compare alternative courses of action (Vergara-Solana et al., 2019). Each MCDA approach involves different protocols for eliciting inputs, structures to represent them, algorithms to combine them, and processes to interpret and use formal results in actual advising or decision-making contexts. For example, MCDA can use focus groups, surveys, and other techniques to formally integrate the opinions of local community groups and other stakeholders into the decision-making process (Linkov et al., 2006).

Probabilistic and statistical methods, including mathematical models, are used for analysis and decision-making under uncertainty, and the computer makes possible many practical applications. Vergara-Solana et al. (2019) review 24 studies that have employed MCDA methods to address aquaculture problems. Their review lists diverse methods to address problems with multiple objectives or criteria. In aquaculture, the techniques applied include multilevel dynamic models, objective programming, nonlinear programming, compromise programming, analytic hierarchy process, and geographic information system tools. MCDA methods have recently been applied to aquaculture in supplier selection, financial risk control, strategic planning or sectoral analysis, optimization of public policy, operation optimization of productive units, selection of species for domestication, project impact assessment (Vergara-Solana et al., 2019), and production site selection (Ghobadi et al., 2021). Empirical applications in the fisheries sector include analysis of group negotiations in fisheries co-management (Hayes and Wainger, 2022) and fisheries management, assessment, and conservation (Estévez and Gelcich, 2015; Rossetto et al., 2015).

4.1.2. Cost-benefit analysis

Cost-benefit analysis (CBA) is a formal technique for making informed decisions on the use of scarce resources (Boardman, 2011; Brent, 2006; Mishan and Quah, 2020). It systematically and analytically compares economic benefits and costs in evaluating the desirability of policies, projects, or programs, often of a social nature; if the economic benefits of a policy exceed the costs, the policy is worthwhile and should be pursued (Rudd et al., 2003). To improve societal welfare, policies with higher ratios of benefits to costs should be pursued first.

According to Boardman (2011), conducting a CBA involves nine basic steps: (1) specify the set of alternative projects; (2) decide whose benefits and costs matter; (3) identify the impact categories, catalogue them, and select measurement indicators; (4) predict the impacts quantitatively over the life of the project; (5) attach monetary values to all impacts; (6) discount benefits and costs to obtain present values; (7) compute the net present value of each alternative; (8) perform sensitivity analysis; and (9) make a recommendation.

The CBA method has been widely applied in evaluating environmental policy (Cullen, 1994; Pearce, 1998; Pearce et al., 2006). It evaluates in monetary terms the costs and benefits—such as health impacts, property damage, ecosystem losses, and welfare effects—of policies and programs. Some benefits or damages occur over the long term, some occur over several generations, and some are irreversible (e.g., global warming, biodiversity losses). The method can be used to estimate impacts on future generations, irreversible losses, and equity or sustainability issues (Pearce et al., 2006). In the absence of market prices, economic benefits are calculated by summing consumer surplus (the difference between what people are willing to pay and what they actually have to pay for an economic commodity) and producer surplus (the difference between a producer's total revenue and total variable cost or, at the margin, between price and marginal cost). Quantifying producer surplus for specific situations requires cost and earning surveys.

In the field of aquaculture and fisheries, CBA has been applied to policy analysis of tropical marine reserves to demonstrate whether marine reserves lead to sustained socioeconomic benefits (Rudd et al., 2003). Marine reserves are considered to be a central tool for marine ecosystem-based management in tropical inshore fisheries. The policy analysis in Rudd et al. considered the full range of economic costs and benefits, including the impact of social capital on the costs of managing fisheries, and the transaction costs of fishery management (e.g., planning and reaching agreements about marine reserve configuration and rules, monitoring, enforcement, and ex post opportunism such as free riding and rent-seeking). Ecological services or amenities provided by marine reserves are considered economic commodities with a price based on their marginal use and nonuse values, and thus generate a consumer surplus even though they are not traded in established markets.

Rudd et al. (2003) find that, among the empirical challenges of using CBA, many ecosystem services provided by marine reserves are nonmarket in nature and difficult to value, especially in developing countries with limited funds for economic studies. Additionally, data on appropriately disaggregated costs of fisheries management and governance are unavailable in many developing countries. Moreover, evidence quantifying the ecological benefits of marine reserves is relatively sparse because of the ad hoc design of many reserves and the inherent difficulties of ascertaining causal links in the marine environment.

4.1.3. SWOT analysis

SWOT (strengths, weaknesses, opportunities, and threats) analysis uses a framework of internal strengths and weaknesses, and external opportunities and threats as a simple way to assess how best to implement a policy or strategy (Start and Hovland, 2004). SWOT analysis can be used at many different stages of a policy process or project to structure a review or discussion before planning. It can be applied broadly, or a small subcomponent of the strategy can be singled out for detailed analysis.

Assessing the current state of a policy or project requires an assessment of internal capacity which reveals the existing resources, skills and abilities, and the current problems. An assessment of the external environment focuses on what is going on outside the policy process or project, or on areas that do not yet affect the strategy but could do so—either positively or negatively. According to Start and Hovland (2004), the following guiding questions are helpful in carrying out a SWOT analysis of a project. What type of policy influence does the project currently do best? Where has it had the most success? What types of policy influencing skills and capacities does the project have? In what areas have they been used most effectively? Who are the strongest allies in policy influence? When have they worked with the project to create policy impact? What are the main strengths and weaknesses of the project? Why? What opinions do others outside the project hold?

Babatunde et al. (2021a) reviewed literature on qualitative SWOT analyses applied to aquaculture and fisheries in Africa, and Rimmer et al. (2013) conducted a review and qualitative SWOT analysis of aquaculture development in Indonesia. A major input in Rimmer et al. was a background study of the policy, economic, environmental, social, and technical elements of aquaculture development in Indonesia, from which areas for aquaculture policy development were identified. Other examples of qualitative SWOT analyses include studies of the food system in Madagascar (Sarter et al., 2010), and fish health and aquaculture sustainability in Turkey (Kayıs, 2019). As part of their review, Babatunde et al. (2021a) also conducted a quantitative SWOT analysis of key aquaculture players in Africa, which was used to determine the competitive position of the aquaculture sectors of the compared countries (Egypt, Nigeria, South Africa, and Uganda) as a basis for aquaculture policies and road maps. Another study conducted a quantitative SWOT analysis of key aquaculture species in South Africa (Babatunde et al., 2021b).

4.1.4. Bioeconometric and bioeconomic models

Economic or econometric models have been widely employed in quantitative analysis for economic policy evaluations (Abbring and Heckman, 2008) and applied in the study of aquaculture production and its sustainability (Peñalosa Martinell et al., 2020). *Econometrics* is the application of mathematical statistics to economic data to give empirical support to models constructed by mathematical economics and to obtain numerical results (Wooldridge, 2015). Thus, an *econometric model* is a representation of an economic system that uses empirical data based on statistical inferences to give sustenance to economic theory. The econometric model is designed to fit the data observed in real situations with the aim of obtaining analytic parameters that adjust to real-world observations, mainly using theoretical bases to establish functional relationships, statistical models, and inference. An *economic model*, by contrast, is a conceptual (or theoretical) model that allows analyzing the behavior of a complex system by using differential equations (Peñalosa Martinell et al., 2020). An econometric model applied to biological systems is called a *bioeconometric model*, because it considers the biological characteristics of cultured organisms (such as growth or mortality), the economic aspects, and the interaction between them (Llorente and Luna, 2016). A *bioeconomic model* consists of a biological model, which describes the production system, and an economic model, which relates the production system to market prices and resource constraints (Cacho, 1997). In many cases, theoretical (bioeconomic) models are parameterized by econometric techniques using data obtained in an experiment.

Bioeconomic models have wide applications in aquaculture as a crucial tool for improving the efficiency of decision-making processes (Llorente and Luna, 2016). They consist of the use of mathematics to model the behavior of biological systems conditioned by biological, environmental, economic, and technical factors. They allow a wide range of simulations, predictions, and necessary analyzes to optimize sustainable production of a business in an increasingly competitive industry. Several studies have applied bioeconomic models in fisheries research (Anderson and Seijo, 2010; Pascoe et al., 2016; Prellezo et al., 2012) and aquaculture (Bunting et al., 2013; Bunting and Shpigel, 2009; Cacho, 1997; Duarte et al., 2022; Janssen et al., 2017).

4.1.5. Computable general equilibrium simulation models

Computable general equilibrium (CGE) models are systems of equations that represent both the production and consumption sides of all markets in the economy, and the prices and trade volumes that make those markets clear. A multisector CGE model can be used for simulation and quantitative analysis of the effects of policies and external shocks on the domestic economy. The social accounting matrix, which portrays the system of interindustry links in the economy, provides the conceptual framework for linking together different components of the CGE model (Robinson et al., 1999). That matrix provides a schematic portrayal of the circular flow of income in the economy: from activities and commodities, to factors of production, to institutions, and back to activities and commodities (Robinson et al., 1999). The presentation of equations of the core CGE model follows this same pattern of income generation. The empirical CGE model is usually developed and implemented in the software General Algebraic Modeling System, which is designed to make complex mathematical models easier to construct and understand. The model is written as a set of simultaneous equations, most of them nonlinear, and the equations define the behavior of the different actors. The CGE model framework can be applied to different settings: the world (divided into multiple regions), countries or regions within countries, villages, and even households (Lofgren et al., 2002). For example, the Rural Investment and Policy Analysis model, developed by the International Fund for Agricultural Development and International Food Policy Research Institute, can be used as a simulation laboratory for building macro-models. However, quality data and key parameters are needed from other tools such as stakeholder mapping, value chain analysis, production system differentiation, and market outlook modeling.

CGE models have been widely applied in economic analysis to analyze feedback effects of policy measures across sectors and regions. Empirical applications of CGE models to aquaculture include the following studies that calibrated CGE models using primary data obtained from rural household surveys in aquaculture zones. Filipski and Belton (2018) used a local economy-wide impact evaluation model, which nests fish farm models within a general equilibrium model of the local economy, to examine the impact of aquaculture on the incomes and labor market outcomes of rural households in Myanmar. Gronau et al. (2020) used a village CGE model to investigate whether aquaculture improves local livelihoods and potentially counteracts local overfishing in a rural region in Namibia with current problems of malnutrition, poverty, and fish resource overexploitation.

Other applications of CGE models to aquaculture and fisheries include studying the gains of integrating sector-wise pollution regulation in Danish crop production and aquaculture (Jacobsen et al., 2016); the effects of aquaculture expansion and increased input productivity on poverty reduction in Ghana, Kenya, and Tanzania (Kaliba et al., 2007); and, in the United States, the impacts of shocks to Alaskan fisheries (Seung and Waters, 2010; Waters and Seung, 2010) and the interactions between aquaculture and capture fisheries in the context of ecosystem-based management in coastal New England (Jin, 2012).

4.1.6. Multilevel models

Multilevel models, also called multidimensional or hierarchical models, are used to analyze data with a hierarchical or nested structure; response variables are measured at the lowest level of the hierarchy and modeled as a function of predictor variables measured at that level and higher (Wagner et al., 2006). For example, a multilevel data structure may consist of measurements taken on individual fish (lower level) nested within lakes or streams (higher level). The standard econometric methods of analysis for cross-sectional or longitudinal data are applied to estimate multilevel models, often using generalized least squares methods (Yang and Schmidt, 2021).

According to Peugh (2010), conducting multilevel modeling analyses involves seven major steps: (1) clarifying the research question under investigation, (2) choosing the correct parameter estimation method (e.g., full information or restricted maximum likelihood), (3) assessing whether multilevel modeling is needed, (4) building the lower-level model, (5) building the higher-level model, (6) reporting multilevel effect sizes, and (7) testing competing multilevel models using the likelihood ratio test.

Fisheries research has employed multilevel models that account for multilevel data structures as a framework for modeling and statistical analysis in fisheries biology (Wagner et al., 2006), to study fisheries discards (Viana et al., 2013), or as a decision support model (Pan et al., 2001). Some applications in aquaculture (Sylvia and Anderson, 1993; Sylvia et al., 1996) have aimed at generating economic policy information for salmon aquaculture policy development in the United States, using a dynamic multiobjective, multilevel policy model for net-pen aquaculture development with effluent taxes as a policy instrument.

4.2. Tools for ex post assessment of existing policy

The following tools, methods, or approaches can be employed for policy evaluation or to legitimize policy choices that have already been adopted.

4.2.1. Impact assessments

The *impact assessment* process aims to structure and support the development of policies (Malvarosa et al., 2019). Impact assessment has six well-established forms: (1) policy impact assessment, (2) environmental impact assessment, (3) strategic environmental assessment, (4) social impact assessment, (5) health impact assessment, and (6) sustainability assessment (Pope et al., 2013). It involves assessing distinct alternatives to achieve a specified policy objective, providing the basis for choosing the policy with the best net benefit. Current practice in impact assessment uses various analytical tools to evaluate the social, economic, and environmental dimensions of sustainable development, for example, using the sustainable development indicators, quantitative models, and participatory approaches, including stakeholder involvement (Bezlepkina et al., 2011; De Smedt, 2010; Morgan, 2012; Morris and Therivel, 2001).

According to a review by Adelle and Weiland (2012), policy assessment most commonly includes regulatory impact assessment and sustainability impact assessment. These broad types of policy assessment in turn harness a range of policy assessment tools and methods such as CBA, scenario analysis, and computer modeling. Policy assessment seeks to inform decision-makers by predicting and evaluating the potential impacts of policy options. Among many existing systems, the European Commission's Impact Assessment system is identified as the leading way of conducting policy assessment in Europe (Adelle and Weiland, 2012; Podhora et al., 2013). It is considered a very integrated assessment system because it includes social, economic, and environmental impacts both inside and outside the European Union (EU) of the EU's most significant policies.

Empirical applications to aquaculture include environmental impact assessments of aquaculture projects (Rodríguez-Luna et al., 2021). In fisheries, empirical work includes a sustainability impact assessment (Malvarosa et al., 2019), an evolutionary impact assessment (Laugen et al., 2014), economic impact assessments (Leung and Pooley, 2001; Torell et al., 2020), and social impact assessments (Feeney, 2013; Hattam et al., 2014; Hiruy and Wallo, 2018).

4.2.2. Comparative advantage assessment approaches

Comparative advantage, an economic concept that helps characterize resource allocation and specialization patterns, reflects the difference between benefits and (opportunity) costs. For example, the more specialized a country is in a market compared to other countries, the greater comparative advantage it has in that market (Cai and Leung, 2008). Comparative advantage provides useful information for policy decision-making, such as a basic explanation of the international pattern of specialization in production and trade, or guidelines for government policies on resource allocation and trade (Cai and Leung, 2008). For instance, assessing a country's comparative advantage in different aquaculture activities can provide useful information for decision-making regarding efficient resource allocation in aquaculture development.

Comparative advantage assessment has two common approaches: the *domestic resource costs* (DRC) approach and the *revealed comparative advantage* (RCA) approach, reviewed in detail by Cai and Leung (2008). The DRC approach uses social profitability to measure comparative advantage—the greater the profitability, the stronger the advantage (Cai and Leung, 2008). Social profitability needs to be gauged under "shadow" instead of market prices. As opposed to observable market prices, shadow prices are social prices reflecting the value of social benefits or costs. Empirical DRC analyses for policy decision-making are often conducted using the policy analysis matrix approach (Cai and Leung, 2008; Hutajulu et al., 2019).

The RCA approach uses ex post specialization patterns to infer comparative advantage patterns—that is, a country's actual high specialization in an activity implies that it has strong comparative advantage in that activity (Balassa, 1965). It is called "revealed" (as opposed to actual) comparative advantage because, rather than reflecting true comparative advantage, high specialization could reflect the influence of policy interventions or distortions such as tariffs or other trade barriers (Cai and Leung, 2008). RCA provides a systematic framework for comparing specialization patterns across countries. The most widely adopted RCA index in empirical studies is the standard Balassa's RCA index (Balassa, 1965).

Aquaculture- or fisheries-related empirical applications of the DRC approach have studied the comparative advantage of Asian countries in shrimp exports (Ling et al., 1999); the comparative advantage of shrimp farming in Asia (Shang et al., 1998); the competitiveness of eel aquaculture in China, Japan, and Taiwan (Lee et al., 2003); economic policy in the development of capture fisheries in Jayapura City, Indonesia (Hutajulu et al., 2019); the competitiveness of fish farming in Nigeria (Osawe and Salman, 2016); and the effects of input policies on the profitability of fish farming in Nigeria (Adesiyan, 2017); and the impact of different policy options on profits of private catfish farms in Arkansas, United States (Kaliba and Engle, 2003). Empirical applications of RCA approaches in aquaculture include studies assessing the export performance of major cultured shrimp producers in the Japanese and US markets (Ling et al., 1996), and US antidumping petitions and RCA of seven shrimp-exporting countries (Chang et al., 2019).

4.2.3. Life cycle assessment

Life cycle assessment (LCA) also has applications in aquaculture. An ISO-standardized methodology, LCA quantifies the impacts on ecosystems, human health, and natural resources of products and systems throughout their entire life cycle—that is, from the extraction of raw materials through their production and use or operation up to their final decommissioning and disposal (Bohnes et al., 2019). It also compiles and evaluates the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle (Hellweg and Milà i Canals, 2014). It is useful for identifying the environmental hot spots of aquaculture systems and comparing them with respect to their embedded environmental impacts. Doing so can provide useful information to policymakers and decision-makers when it comes to encouraging development of specific types of farm installations or introducing regulations on excessively polluting processes. Identification of environmental hot spots helps to focus development of more eco-efficient aquaculture systems and can also help consumers select products that meet minimum environmental requirements.

Bohnes et al. (2019) reviewed studies of several seafood farming systems to quantify their impacts on the environment. The studies conducted quantitative analyses to explore which impacts can be identified as dominating and to compare different types of aquaculture systems. On the basis of their review, Bohnes et al. provide recommendations to decision- and policymakers in the aquaculture sector. They recommend the systematic use of LCA in the design of new aquaculture systems or policies, or in the evaluation and optimization of existing ones, to promote an environmentally sustainable aquaculture sector.

Ziegler et al. (2016) noted the use of LCA to quantify environmental impacts of products throughout their supply chain. Through their review of studies with empirical applications of LCA to fisheries management, Zieglar et al. divided LCA into five steps: (1) define product, goal, and specific methods; (2) collect specific and generic data on resource use, production, and emissions in each step; (3) calculate results for example emissions; (4) analyze results, sensitivity, or uncertainty and revisit steps 1–3 if needed; and (5) apply the results in policy support, fisheries management, creating sourcing strategies, product development, or certification. Other literature reviews have looked at methodologies and LCA of aquaculture systems (Henriksson et al., 2012) and the use of LCA for the environmental assessment of fisheries (Avadí and Fréon, 2013; Evans et al., 2011).

4.3. Tools for mapping and understanding policy processes

The following tools, methods or approaches can be employed ex ante or ex post to understand policy processes, policy development, and policy implementation.

4.3.1. Social network analysis

The *social network analysis* (SNA) method is used to map policy processes, analyze policy networks, and examine policy implementation (Fischer, 2011; Mischen and Jackson, 2008; Serrat, 2017). It focuses on social relationships and uses a wide range of methods to describe the structure of networks and people's places within those networks (Schiffer and Waale, 2008). Its underlying idea is that the structure of networks determines both the success of the individual and how an organization or society acts and develops. As such, SNA tries to understand social and political situations by focusing on their formal and informal structures (Aberman et al., 2009). Because of its focus on relations among actors, it tends to study whole populations by means of census, rather than by sample. When the population is too large for a census, snowball methods or purposeful sampling are recommended (Aberman et al., 2009). To understand the policy process, studies can also employ standard survey research methods such as literature review, semi-structured interviews with key policy actors, or focus group discussions with local stakeholders (Chambers et al., 2012; Okello et al., 2015).

Some empirical policy analysis studies using SNA have been based on the work of the International Food Policy Research Institute. For example, Schiffer and Waale (2008) used SNA to study multistakeholder water governance in the White Volta Basin of Ghana. They developed an innovative empirical research tool (Net-Map) to better understand multistakeholder governance by gathering in-depth information about governance networks and goals, power, and influence of actors. The Net-Map tool, which combined social network visualization with the power-mapping tool that collects data about the perceived power of different actors within a policy field, collected qualitative and quantitative information in a structured and comparable way. Similarly, Aberman et al. (2009) used SNA to study Nigeria's fertilizer policy process and the role evidence-based research played in it. They used the Net-Map tool by combining SNA with principles of power mapping and stakeholder analysis approaches. Their examination of the policy process allowed them to trace how the actual policy process took place, the actors involved and the links and interactions between them, and the degree to which research-based information played a role in the policy development. Schiffer and Hauck (2010) present a detailed description of Net-Map.

Policy network analysis (Rhodes, 2008)*,* another form of SNA, has been employed in understanding governance structures for implementation of marine environmental policy in the United Kingdom (Bainbridge et al., 2011). In that study, it provided an insight into the balance and patterns of responsibility, accountability, authority, resources, relationships, and power in the policy process, and enabled an understanding of policymaking and implementation.

Empirical applications of SNA in aquaculture have studied key players in salmon aquaculture development in Canada (Maxwell and Filgueira, 2020), the effect of social and economic drivers on choosing aquaculture as a coastal livelihood in Tanzania (Slater et al., 2013), the impacts of aquaculture on social networks in the mangrove systems of northern Vietnam (Orchard et al., 2015), the effect of network-based targeting on the diffusion of good aquaculture practices among shrimp producers in Vietnam (Lee et al., 2019), and the international trade network of aquatic products (Yu and Ma, 2020). SNA has also been used to study networks and collaborations among researchers in fisheries science (Olson and Pinto da Silva, 2021), for mapping the global network of fisheries science collaboration (Syed et al., 2019), to study fishery management as a governance network (Hartley, 2010), and to study how social networks support or constrain the transition to co-management of small-scale fisheries and marine reserves in Jamaica (S. M. Alexander et al., 2015).

4.3.2. Stakeholder analysis

Stakeholder analysis is used for generating knowledge about actors (individuals and organizations) so as to understand their behavior, intentions, interrelations, and interests, and for assessing the influence and resources they bring to decision-making or implementation processes (Varvasovszky and Brugha, 2000). Incorporating stakeholders' opinions improves decision-making processes and project implementation (Kivits, 2011). Stakeholder analysis can be used, for example, to conduct a comprehensive policy analysis that produces new knowledge about policy-making processes, and to predict policy development, implement a specific policy, or obtain an organizational advantage in one's dealings with other stakeholders (Varvasovszky and Brugha, 2000). The scope of its application in policy analysis can range from understanding the roles of stakeholders in the evolution of the policy context and processes, to outlining more long-term and broadly-focused policy directions (Varvasovszky and Brugha, 2000).

Conducting a policy analysis requires first identifying the different components of the policy issue or problem; stakeholder analysis can then be used to map the positions of the actors in relation to the problem and each other. Stakeholders—the actors who have an interest in the problem under consideration, are affected by the problem, or have (or could have) an active or passive influence on the decision-making and implementation processes—can include individuals, organizations, different individuals within an organization, and networks of individuals and/or organizations such as alliance groups. Data collection for stakeholder analysis uses primary sources (such as face-to-face interviews using checklists, semi-structured and structured interviews, and focus group or informal discussions) and/or secondary sources. Findings may be presented using matrices, charts, position maps, network maps, or figures.

In AqFS research, stakeholder analysis has been employed in empirical analyses of sustainable aquaculture development (Bunting, 2010), integrated multitrophic aquaculture (Alexander et al., 2016), ecosystem-based marine aquaculture expansion (Galparsoro et al., 2020), supply chains of trout and seabass in Italy (Mulazzani et al., 2021), Norwegian aquaculture (Bailey and Eggereide, 2020; Chu et al., 2010), marine fisheries management in Southeast Asia (Pomeroy et al., 2016), the UK's agricultural and fisheries systems under Brexit (Stewart et al., 2019), fishery stakeholder engagement and marine spatial planning in the United States (Nutters and Pinto da Silva, 2012), and marine aquaculture partnerships in the United States (Siddiki and Goel, 2015),.

4.4. Other tools that can inform policy design

The following tools, methods, or approaches can be employed ex ante to support policy design and development, support policy processes, and provide important information for policy decision-making.

4.4.1. Value chain analysis

A *value chain* describes the full range of activities required to bring a product or service from conception, through the different phases of production, distribution to consumers, and final disposal after use (Porter, 1985). The value chain is the basic tool for diagnosing and enhancing competitive advantage; it divides a firm into the discrete activities it performs in designing, producing, marketing, and distributing its product (Porter, 1985). *Value chain analysis* (VCA) is important for policy and practice because understanding value chains in an industry allows policymakers and practitioners to provide relevant and appropriate support to local enterprises so they can compete in the global economy, and to improve the earning opportunities for local people (Schmitz, 2005). International competitiveness of local enterprises requires an effective domestic value chain. VCA provides a framework for sector-specific action because it can help policymakers identify bottlenecks and determine which bottlenecks deserve priority attention from government (Schmitz, 2005).

Kaplinsky (2004) notes three analytical components of VCA that can reveal distributional and policy implications: (1) the dynamics of rents within the chain, (2) the governance of the chains, and (3) the systemic and transnational character of the chains (systemic efficiency gains). Therefore, VCA can throw more light on the dynamics of income distribution and its determinants. The dynamic shifting of producer rents through the value chain, and the processes through which key actors provide governance to production that occurs on a global basis, provides important insights into the policy challenges confronting both private and public actors.

Global VCA has been widely used as an analytical tool to explain the dynamics of economic globalization and international trade, and the wide variation of benefits accruing (or not) from participation in different value chains (Bush et al., 2019; Kaplinsky, 2004). VCA provides valuable insights into policy formulation and implementation by charting the growing disjuncture between global economic activity and global income distribution and the causal explanations for this outcome (Kaplinsky, 2000). It can be used to map and analyze value chains, using qualitative and/or quantitative research tools such as participant observation, semi-structured interviews, focus group discussions, and questionnaires (Hellin and Meijer, 2006).

Empirical applications of VCA in fisheries include the assessment of power, profits and payments for ecosystem services in Hilsa fisheries in Bangladesh (Porras et al., 2017); the farmed tilapia value chain in Ghana (Anane-Taabeah et al., 2016); seasonal flows of economic benefits in small-scale fisheries in Liberia (Jueseah et al., 2020); gender analysis of the aquaculture value chain in Nigeria and northeast Vietnam (Veliu et al., 2009); small-scale fisheries management (Rosales et al., 2017); the distribution of economic returns in small-scale fisheries for international markets (Purcell et al., 2017); tourism as a driver of conflicts and changes in fisheries value chains in marine protected areas (Lopes et al., 2017); and upgrading and exploitation in the fishing industry (Hamilton-Hart and Stringer, 2016). In aquaculture, VCA has been employed in mapping the tilapia aquaculture value chain in Ghana (Asiedu et al., 2016) and in studying the aquaculture feed sector in Egypt (El-Sayed et al., 2015), gender and aquaculture value chains (Kruijssen et al., 2018), aquaculture value chains in Asia (Jespersen et al., 2014; Ponte et al., 2014), and commercialization and upgrading in the aquaculture value chain in Zambia (Kaminski et al., 2018).

4.4.2. Machine learning techniques

Machine learning is the study and computer modeling of learning processes in their multiple manifestations (Carbonell et al., 1983). It and data mining are branches of artificial intelligence that use the explosive growth in data to analyze the association between causes and effects, predict imminent problems, and provide solutions (Gladju et al., 2022). *Data mining* is the computing process of discovering patterns and extracting useful information from large data sets, whereas *machine learning* is the ability of a computer to use complex algorithms and learn from mined data sets without being exclusively programmed (Gladju et al., 2022). Machine learning takes data as given, without any theoretical assumptions about the relationship between different variables; the computer then tries to identify patterns and transfers these findings into a computational model.

Several recent studies have applied machine learning techniques to aquaculture and fisheries. As reviewed by Gladju et al. (2022), empirical applications of machine learning techniques in aquaculture include monitoring and control of production environment, fish biomass, and optimization of feed use. In fisheries management, empirical applications include the surveillance of fishing, catch composition, and ecosystem-fisheries associations. Other applications relate to environment monitoring, fish processing, and marketing. More examples of empirical applications include mapping aquaculture waterbodies in Bangladesh (Ferriby et al., 2021), studying smart aquaculture systems (Vo et al., 2021), recirculating aquaculture systems in China (Chen et al., 2021), prediction models of aquaculture in Malaysia (Rahman et al., 2021), studying environmental impacts of salmon farming in Norway (Frühe et al., 2021), and studying intelligent fish aquaculture, including the information evaluation of fish biomass, the identification and classification of fish, behavioral analysis, and prediction of water quality parameters (Zhao et al., 2021).

5. Policy issues, policy solutions, and lessons from AqFS research

This section examines the policy issues, policy solutions, and lessons emerging from the literature on policy analysis and evaluation. Two kinds of policies are analyzed or evaluated in the literature. One type consists of broad policies—legal documents with a set of visions and broad objectives at the regional, national, or subnational level, (e.g., the CFP, national aquaculture or fisheries policies). Such policy analysis often involves policy content analysis, policy implementation, and policy impact analysis (ex ante and ex post). The other type consists of specific policies—specific laws, legislation, or legal procedures that directly affect prices, impose costs, and provide a financial incentive or penalties for violations (e.g., input subsidies, import restrictions, individual transferable quotas). The rest of this section presents selected case studies illustrating these types of policy analysis and evaluation. Annex 3 presents a summary table with empirical case study examples on policy analysis and evaluation in AqFS.

5.1. Policy content analysis

Policy content analysis in AqFS research has examined inconsistencies or conflicting policies, and whether policies are up to date or consistent with international or regional policies. The results demonstrate the importance of aligning national AqFS policies with those of public health and nutrition in order to achieve the objectives of increasing food security and AqFS sustainability (Koehn et al., 2022). In addition, realizing the potential contribution of aquatic foods such as nutrient-rich fish and shellfish to healthier food systems will require more targeted and systematic policy approaches. The literature acknowledges the importance of development partners in designing better national policies. For example, Koehn et al. (2022) find that the presence of development partners in a country results in a higher probability of cross-sector integration of its fisheries and public health nutrition policies. This finding suggests that development agencies such as FAO and WorldFish, which promote aquatic foods in healthy diets, help to improve the level of inclusion between fisheries and health policies.

Evaluations of national aquatic food policy documents (enacted laws and policies) in many countries reveal unequal distributions of benefits in the global food system, which are associated with barriers to participation in AqFS (Hicks et al., 2022). The unequal distribution of AqFS benefits is equated to social injustice: whereas global production, trade, and consumption of food have escalated, the AqFS sectors have become more concentrated and the number of food-insecure people continues to rise. Dynamics that can lead to poverty traps are created by economic barriers associated with distributional injustices that limit wealth-based benefits but create welfare-based dependencies with livelihoods more dependent on the AqFS. National policies have mainly addressed economic barriers related to wealth and trade (particularly in southern Africa) and, to a lesser extent, the political or social barriers (such as gender and age) to participation in AqFS. A focus on overcoming economic barriers in the production of aquatic foods and social barriers in the consumption of aquatic foods is likely to reinforce divisions of labor shaped by traditional social and cultural norms.

The literature emphasizes the importance of gender equality considerations in AqFS policy and sustainable development. For example, to study the efficacy of gender equality priorities, intentions and impacts, Lawless et al. (2022) evaluated the policies and practices that influence small-scale fisheries in the Pacific Islands. Gender equality is considered a determinant of social resilience, adaptive capacity, and social-ecological and environmental outcomes. Lawless et al. find that policy commitments to gender equality, although common, often become diluted and reoriented in practice. In order to drive communal- to societal-level change, AqFS policy and practice need to adequately confront the challenges of rising social inequality, and of maintaining stable and resilient socio-ecological systems.

The literature highlights pollution of marine ecosystems as one of the most serious forms of environmental degradation, which requires regulatory efforts by both domestic and international policymakers. Using a case study of election manifestos of political parties in Germany, Tosun (2011) examined questions about how much attention policymakers pay to the issue of marine pollution, how the level of attention has changed over time, and whether policy proposals focus on national or global marine ecosystems. Their empirical findings suggest that policymakers have consistently acknowledged the need to protect marine ecosystems and that marine policy proposals need a more global scope. Thus, domestic political actors do elaborate policy options for reducing marine pollution, even though it is a predominantly transboundary problem. The level of attention to the problem of marine pollution depends, however, on the marine policy agenda, which varies considerably across political parties.

Some studies have assessed the policy design and interpretation of aquaculture policies. For example, a case study in Florida and Virginia examined the relationships between policy legitimacy, coerciveness, and enforcement in affecting policy interpretations (Siddiki, 2014). The results provide insights into the policy- and decision-making processes: (1) perceptions of regulatory coerciveness largely depend on the substantive focus of individual directives; (2) lenient enforcement of regulations leads to more relaxed interpretations of directives; and (3) perceptions of policy legitimacy sometimes temper perceptions of policy coerciveness.

Other studies have evaluated the regulatory and governance frameworks for aquaculture. These frameworks are becoming more inclusive by providing for civil engagement in the context of the marine environment. For example, Peel and Lloyd (2008) analyzed the broad range of environmental and consumer regulations associated with aquaculture production in Scotland and the introduction of statutory planning controls over the development of aquaculture installations. They found evidence of an explicit attempt to design appropriate forms of governance that are open, participative, accountable, coherent, and effective. Their results indicate that the regulation of aquaculture is maturing into a potential form of modern governance and includes evolving state–market–civil relations and the particular institutions associated with planning and governance.

5.2. Policy implementation evaluation

Policy implementation evaluations in the literature have analyzed broader national policies such as the EU's CFP, which has received much attention and criticism in the literature regarding its implementation and impact. The CFP is criticized for legitimacy, credibility, and compliance problems (Linke et al., 2011). It has been criticized for not fulfilling its aim of enhancing the sustainability of fish stocks or improving the economic competitiveness of the fishing industry in the EU (Daw and Gray, 2005; Khalilian et al., 2010), despite EU government reforms aimed at enhancing governance quality (Aguado et al., 2021; Frost and Andersen, 2006; Salomon et al., 2014). For instance, a 2002 revision was to involve fisheries representatives, nongovernmental organizations, and other stakeholders in the policy process through Regional Advisory Councils, however current practice only peripherally includes stakeholders in the knowledge-generation stage (Linke et al., 2011). While in 2009, the most important reform steps were the introduction of maximum sustainable yield as the new management target, a landing obligation for bycatch, and a governance shift toward regions (Salomon et al., 2014). However, marine populations in Europe are declining due to problems such as lax enforcement of fisheries management by state members and high economic losses experienced by fishers and coastal communities (Da Rocha et al., 2012). Europe's coastal fisheries are under increasing stress from internal and external pressures for change (Davies et al., 2019). In response to the failures of the CFP, proposals for effective fisheries governance include new governance mechanisms and policy solutions such as stakeholder participation in decision-making processes, co-governance, interactive governance, and knowledge integration (Aguado et al., 2021; Linke et al., 2020, 2011; Symes, 2006; 2015). Developing spaces for dialogue and evolving shared norms within participatory, democratic, and flexible governance processes will facilitate collaboration among stakeholder groups at different institutional levels (Aguado et al., 2021). Doing so will likely increase the credibility, legitimacy, and acceptance of fisheries policies, thereby enhancing fisheries governance quality and sustainability.

Other studies have evaluated implementation of national policies on marine conservation. For example, *Marine protected areas* (MPAs) are proclaimed as powerful policy tools for biodiversity conservation of marine areas, wildlife and habitats, and fisheries management (Edgar et al., 2014). MPAs are sections of the ocean where a government has restricted fishing and other human activities to conserve habitats and populations (Balmford et al., 2004). Establishing and maintaining MPAs should be a priority for all countries, especially those that have committed to protecting at least 10 percent of their marine habitats by signing the United Nations Convention on Biological Diversity (Chandra and Idrisova, 2011). However, MPAs are sometimes challenged for the social impacts and conflicts they may generate (Agardy et al., 2003). For example, in the archipelago of Fernando de Noronha MPA of Brazil, Lopes et al. (2017) found that tourism drove conflicts and changes in fisheries value chains. They recommended setting stricter limits to the number of tourists visiting the MPA in order to avoid conflicts with conservation goals through incentives for increased resource use. Other MPAs—such as marine reserves, in which removing or destroying natural or cultural resources is prohibited—can be efficient policy options when both community and state capacity are high, but may not be when one or the other is weak (Rudd et al., 2003). Determining the proper balance of the state and the community in tropical fisheries governance requires broad comparative studies of marine reserves and alternative policy tools.

5. 3. Policy impact analysis

Policy impact analyzes in the literature have evaluated impacts of aquaculture and fisheries policies. For example, Read and Fernandes (2003) evaluated the environmental impacts of marine aquaculture policies and regulations in the EU. The strategy and regulatory framework for the regulation, control, and monitoring of environmental impacts of marine aquaculture within the EU indicates that adopting appropriate environmental safeguards—including regulatory, control, and monitoring procedures—could minimize the environmental impact of aquaculture. In the EU, that impact is managed through the implementation of legislative and regulatory measures, codes of conduct, and codes of practice. In practice, compliance with these measures and codes requires the adoption of best practices and best available technology—for example, in site selection, management practices that minimize food waste and chemical usage, synchronized production, fallowing, and disease control. The legal and regulatory framework used to manage aquaculture activities in the EU are developed in response to national needs and international requirements. Environmental provisions have been introduced into all policy areas in order to emphasize the importance of environmental protection. For marine aquaculture, environmental protection measures have been established at three levels: general policy, specific measures, and regulations that control specific local conditions. Directives relevant to marine aquaculture include environmental quality objectives and environmental quality standards. They are also implicated in the integration of aquaculture management through integrated coastal zone management, and in certain procedural formalities involved in setting up aquaculture activities, such as the requirement for environmental impact assessment in the licensing procedures for aquaculture developments.

Another case study analyzes environment policy compliance in fisheries management. Other studies have used economic models in policy evaluations, for example, to study the impact of specific national policies such as input subsidies. Amankwah et al. (2016) used a double hurdle economic model to examine the factors that influence fish farming households' demand for improved feed in the presence of an input subsidy program in Kenya. Their study tested the hypothesis that the feed subsidy program limits a household's market participation decision and the intensity of demand for improved feed. They found that the quantity of improved feed received from the government affects households' decisions to participate in the improved feed market and that, as expected, the price of improved feed negatively affects the quantity purchased. Education, extension contacts, and ease of marketing matured fish increase household propensity to purchase improved feed commercially. Policies to reduce the price of improved feed, such as reductions in tariffs on imported feeds and feed ingredients, are recommended to foster demand for improved feed along with policies that facilitate household marketing of fish at reasonable prices.

6. Conclusion

This study has conducted an extensive review of the frameworks, concepts, tools, methods, and approaches used in the literature to analyze policies and policy-related issues in the fisheries and aquaculture sector. The analysis includes various topics such as aquatic food production, food and nutrition security, conservation, environmental impacts, sustainability, institutions, governance, and national or regional policies. Our review shows that different countries face many policy issues but that analysis on those issues is scarce.

Despite the wide variety of frameworks concepts, tools, methods, and approaches available, only a few of the nonexhaustive and illustrative examples of policy issues and questions in box 1 are investigated in empirical analysis. More research is available on local- and community-level governance of fisheries, and less on national or subnational policies and regulations in AqFS. The few available policy studies focus on developed countries, with fewer applications in developing countries where aquaculture and fisheries sectors have much stronger growth. Those few studies provide useful and insightful policy options and guidance, and this review highlights the need for more such studies to address policy-related issues in the sector.

Rigorous policy impact evaluations are scarce in aquaculture and fisheries, especially in developing countries. Often, the lack of quality data is the bottleneck. Data-driven and evidence-based policy reform and decision-making by stakeholders will require improving the quality of data collection, monitoring systems, and assessment for AqFS from the economic, social, and environmental dimensions and taking advantage of low-cost digital technologies, innovative crowdsourcing, and public-private partnerships.

This review is a timely contribution to the scholarly literature on this subject. This paper provides a discussion and examples of frameworks, tools, and methods that researchers can use to analyze policies and policy-related issues in AqFS. The results provide insights to guide analysts, researchers, and policymakers as they set out to evaluate policy issues, policy processes, and policy impacts.

With the high and growing global demand for aquatic foods, the fisheries and aquaculture sectors need to meet the growing demand for aquatic foods while curbing the negative impacts on the environment and ecosystems. Therefore, appropriate policies, institutions, and governance mechanisms for fisheries and aquaculture remain crucial for achieving growth and sustainability. Moreover, continued growth in the fisheries and aquaculture sector has important implications for global food and nutrition security, poverty reduction and improved incomes, and achieving the United Nations Sustainable Development Goals.

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ANNEX 1. Frameworks applied in policy analysis of AqFS

Framework	Short description	Applications in AqFS
Aquaculture governance framework based on commons perspective	Based on a shared resource or commons perspective to aquaculture for identifying the social and environmental commons creating collective action problems or social dilemmas for aquaculture governance (Partelow et al., 2022); helps conceptualize the origin of governance problems and the analysis of institutional interactions and solutions	Description and analysis of aquaculture governance challenges and institutional diversity challenges within each system: mariculture in Peru, earthen ponds in Philippines, raceway flow-through systems in Nepal, and recirculating aquaculture systems in Denmark
Social-ecological systems (SESs) framework	Provides guidance on how to assess the social and ecological dimensions that contribute to sustainable resource use and management (Leslie et al., 2015); useful for analyzing the sustainability of SES and organizing the findings based on a set of potentially relevant variables	Social-ecological sustainability of fisheries in Mexico and Chile (Basurto et al., 2013; Leslie et al., 2015), pond aquaculture production in Indonesia (Senff et al., 2018), linking fisher perceptions to social-ecological context in Costa Rica (Partelow et al., 2021), analyzing the relationship between people and policy in aquaculture development (Krause et al., 2015)
Interactive governance and governability framework	An alternative framework for understanding the current state of affairs in the fisheries field, and the new directions that could be explored; two points of departure: (1) the increasing diversity, complexity, dynamics, and differences of scale among fisheries systems to be governed, and (2) the notion that governance is not a task of government alone (Kooiman et al., 2005)	Analysis of fisheries governance: a practitioner's guide, and comprehensive academic studies on the topic of fisheries governance (Bavinck et al., 2013; Jentoft and Bavinck, 2014; Jentoft and Chuenpagdee, 2015)
Participatory fisheries governance	Emphasizes democratic engagement and deliberative processes steering the complex set of interactions among stakeholders, with different needs, demands, and interests, whose activities are often managed by multiple agencies and regulations (Aguado et al., 2021).	Analysis of the quality of fisheries governance in Spain using a participatory and multicriteria framework (Aguado et al., 2021), participatory issues in fisheries governance in Europe (Pita et al., 2012), how regional advisory councils can incorporate stakeholder knowledge into fisheries governance (Linke et al., 2011), rights-based fisheries governance (Allison et al., 2012), participation, integration and institutional reform in fisheries governance (Linke et al., 2020), and community empowerment through participatory fisheries research (Wiber et al., 2009)

Framework	Short description	Applications in AqFS
Institutional analysis and development framework	Examines problems that individuals (or organizations) face and how rules address these problems; used for analyzing fisheries management institutions, particularly collective action and problems that individuals (or organizations) face and how rules address the problems (Ostrom, 1990); considers institutional design and performance in the management of common pool resource systems (Ostrom, 2011, 2007).	Analysis of the challenges for the development of environmentally sustainable cage culture farming in Lake Maninjau, Indonesia (Yuniarti et al., 2021), institutional analysis of aquaculture in Galician turbot, Spain (Fernández-González et al., 2020), assessment of policy design and interpretation of aquaculture policies in Florida and Virginia of the US (Siddiki, 2014)
Systems thinking	Provides a methodology to achieve a better understanding of the nonlinear behavior of complex systems and improve the assessment of the consequences of policy interventions (Hynes et al., 2020); based on the belief that component parts of a system will act differently when viewed in isolation from other parts of the same system, so sets out to view whole structures in a holistic manner (Stead, 2019).	Contribution of aquaculture to antibiotic resistance in Vietnam (Brunton et al., 2019); feasibility of potential interventions to reduce antibiotic use in tilapia farming in Egypt (Desbois et al., 2021); stakeholder adaptive capacity to salmon aquaculture policies in Norway (Tiller et al., 2014); marine fisheries management systems in the US (McGuire and Harris, 2011), China (Su et al., 2022) and South Africa (Sowman, 2011); impact of Europe's coastal fisheries policy (Symes et al., 2015); social-ecological links that can inform a transition toward sustainability in small-scale fisheries (Kittinger et al., 2013)

ANNEX 2. Tools or methods applied in policy analysis of AqFS

Tools/methods	Short description	Data requirements/sources	Countries with applications	Applications in AqFS
Multi-criteria decision analysis (MCDA)	Techniques for considering two or more objectives or criteria for a given decision (Howard, 1980); provides a systematic methodology to combine heterogeneous and uncertain technical information into an understandable framework to facilitate decision making (Huang et al., 2011)	Multilevel dynamic models, objective programming, nonlinear programming, compromise programming, analytic hierarchy process) (e.g., in site selection, geographic information system (e.g., for data collection), etc. (see Ghobadi et al., 2021)	Canada, Egypt, India, Iran, Greece, Kenya, Malaysia, Mexico, Philippines, Thailand, United Kingdom, United States	Production site selection, supplier selection, financial risk control, strategic planning or sectoral analysis, optimization of public policy, operation optimization of productive units, selection of species for domestication, project impact assessment
Life cycle assessment	ISO-standardized; quantifies the impacts of products and systems on ecosystems, human health, and natural resources from the extraction of the raw materials through their production and use or operation to their final decommissioning and disposal (Bohnes et al., 2019)	(1) Definition of goal and scope, (2) life cycle inventory, (3) impact assessment (see Henriksson et al., 2012; Ziegler et al., 2016)	Australia, Canada, Denmark, Iceland, New Zealand, Norway, Peru, Portugal, Senegal, Spain, Sweden, United States, Antarctic	Quantifying environmental impacts of aquaculture and seafood production systems; comparing different intensities, technologies, and/or culture types in order to identify the most environmental-friendly ways of producing seafood and in policy support and fisheries management
Cost-benefit analysis	Systematic and analytical process of comparing economic benefits and costs in evaluating the desirability of policies, projects or programs, often of a social nature; formal technique for making informed decisions on the use of society's scarce resources (Boardman, 2011; Brent, 2006; Mishan and Quah, 2020)	(1) Specify the set of alternative projects or policies; (2) decide whose benefits and costs count; (3) identify and catalogue impact categories, and select measurement indicators; (4) predict impacts quantitatively over the life of the project; (5) monetize impacts; (6) discount benefits and costs to obtain present values; (7) compute net present value of each alternative; (8) perform sensitivity analysis (see Boardman, 2011)	Cameroon, Indonesia, Kenya, Norway, Sri Lanka,	Policy analysis to demonstrate whether marine reserves lead to sustained socioeconomic benefits

Tools/methods	Short description	Data requirements/sources	Countries with applications	Applications in AqFS
SWOT (strengths, weaknesses, opportunities, threats) analysis	A simple way to assess how a policy/strategy can best be implemented (Start and Hovland, 2004) through broad application or singling out a small subcomponent of the strategy	Qualitative—background study or literature review detailing internal factors (strengths and weaknesses) and external factors (threats and opportunities) of the policy or project (Rimmer et al., 2013) and stakeholder interviews (Sarter et al., 2010); quantitative—statistical analysis to compare the factors (Babatunde et al., 2021b, 2021a)	Alaska, Egypt, Indonesia, Madagascar, Nigeria, South Africa, Turkey, Uganda,	Aquaculture development and sustainability; fisheries development
Impact assessments	Six well-established forms to structure and support policy development (Malvarosa et al., 2019): environmental impact assessment, strategic environmental assessment, policy assessment, social impact assessment, health impact assessment, and sustainability assessment (Pope et al., 2013)	(1) Scoping and baseline study, (2) description and evaluation of baseline conditions, (3) impact prediction or risk assessment, (4) mitigation and monitoring proposals and prescriptions, (5) presentation of findings and proposals, (6) monitoring.	Chile, Europe, Malawi, Asia Pacific, North America	Environmental impact assessment and sustainability assessment of aquaculture; evolutionary impact assessment of fisheries; social and economic impact assessment of fisheries
Comparative advantage assessment approaches	Characterize resource allocation and specialization patterns; reflect difference between benefits and (opportunity) costs (Cai and Leung, 2008); two common approaches—domestic resource costs (DRC) approach and revealed comparative advantage (RCA) approach	Empirical DRC analyses—based on the policy analysis matrix approach (Cai and Leung, 2008; Hutajulu et al., 2019); RCA approach—standard Balassa's RCA index (Balassa, 1965).	China, Japan, Nigeria, Taiwan, United States	Comparative advantage or export performance, profitability and competitiveness in aquaculture and fisheries
Social Network Analysis	Maps policy processes, analyzes policy networks, and examines policy implementation (Fischer, 2011; Mischen and Jackson, 2008; Serrat, 2017); focuses on social relationships; describes structure of networks and people's places within	Literature review, snowball sampling, semi-structured interviews with key policy actors, or focus group discussions with local stakeholders (Chambers et al., 2012; Okello et al., 2015)	Canada, Ghana, Jamaica, Tanzania, Vietnam,	Social and economic drivers of aquaculture, impacts on social networks; aquaculture development and trade networks; fisheries management and social networks

Tools/methods	Short description	Data requirements/sources	Countries with applications	Applications in AqFS
	them (Schiffer and Waale, 2008).			
Value chain analysis	Looks at full range of activities required to bring a product or service from conception, through production, distribution to consumers, and final disposal after use (Porter, 1985); used to explain the dynamics of economic globalization and international trade (Kaplinsky, 2004; Bush et al., 2019)	Used to map and analyze value chains, using qualitative and/or quantitative research tools (e.g., participant observation, semi-structured interviews, focus group discussions, questionnaires) (Hellin and Meijer, 2006)	Bangladesh, Egypt, Ghana, Liberia, Nigeria, Zambia, Asia	Mapping aquaculture value chains; commercialization and upgrading in aquaculture; fisheries management and economic returns from fisheries; payments for ecosystem services; tourism and changes in fisheries value chains in marine protected areas
Bioeconomic and bioeconometric models	Bioeconomic model—biological model describing production system plus economic model relating production system to market prices and resource constraints (Cacho, 1997); Bio-econometric models—applied to biological systems; consider biological characteristics of cultured organisms, economic aspects, and interaction between them (Peñalosa Martinell et al., 2020)	Depend on the type of research to be conducted: component research (understand mode of action or behavior of components of a production system and its subsystems), systems research (characterizes interactions that occur between components of production system), management research (physical performance, financial returns, and risk in different environments) (see Cacho 1997)	Australia, Indonesia, New Zealand, Nigeria, Norway, European Union	Production, performance, and welfare of species in aquaculture and fisheries
Computable general equilibrium simulation models	Systems of equations that represent production and consumption sides of all markets in the economy, and the prices and trade volumes that make those markets clear (Filipski and Belton, 2018); social accounting matrix (SAM)—conceptual framework for linking together different components of model (Robinson et al., 1999)	Data for SAM from secondary sources or quantitative surveys (Robinson et al., 1999; Lofgren et al., 2002)	China, Denmark, Ghana, Kenya, Myanmar, Namibia, Tanzania, United States, European Union	Welfare impacts of aquaculture on rural households; interactions between aquaculture and capture fisheries; impacts of exogenous shocks to fisheries

Tools/methods	Short description	Data requirements/sources	Countries with applications	Applications in AqFS
Multilevel models (MLMs)	Used for analysis of data with a hierarchical or "nested" structure (response variables measured at the lowest level of the hierarchy and modeled as a function of predictor variables measured at that level and higher) (Wagner et al., 2006)	(1) Clarify research question, (2) choose correct parameter estimation method (i.e., full information or restricted maximum likelihood), (3) assess need for MLM, (4) build level-1 model, (5) build level-2 model, (6) report multilevel effect sizes, (7) test competing multilevel models using likelihood ratio test	Ireland, United States	Aquaculture and fisheries biology; production and development aspects
Machine learning methods	Machine learning—study and computer modeling of learning processes (Carbonell et al., 1983); supervised machine learning (SML) method—focus on prediction, provide data-driven approaches to building rich models, and rely on cross-validation as a powerful tool for model selection.	SML methods or unsupervised learning methods (Gladju et al., 2022)	Bangladesh, China, Malaysia, Norway	Monitoring and control of production environment; fish biomass and optimization of feed use; smart aquaculture, surveillance of fishing; catch composition and ecosystem-fisheries associations; environment monitoring; fish processing and marketing

ANNEX 3. Examples of policy analysis and evaluation studies in AqFS

Policy analysis/studies	Policy issues/problems	Recommended policy solutions
Integrated multitrophic aquaculture (IMTA) in Europe (K. A. Alexander et al., 2015)	Flexibility within current governance frameworks across six European countries to allow for IMTA adoption and management; identifying incentives and barriers to the development of IMTA within Europe	* Develop a dedicated aquaculture policy promoting innovation and technology, and diversifying aquaculture activities; *Simplify the regulatory burden, through the development of one-stop-shop licensing or dedicated spatial planning for aquaculture; * Move focus from single species approach to incorporate biculture and polyculture; and * Develop disease and food safety legislation that directly recognizes IMTA products.
Governance of multiuse platforms at sea (MUPS) for energy production and aquaculture in European seas (Stuiver et al., 2016)	Upsurge in competing marine activities (fisheries, tourism, transportation, and oil production) and infrastructures (offshore windfarms, aquaculture, and tidal and wave energy); high investment costs and risks compared with business-as-usual projects; understanding how governance arrangements may facilitate or complicate MUPs	*Develop clear policy framework at all levels to guide offshore MUPS development, including licensing procedure that adheres to marine spatial planning principles to foster sustainable use of marine space. *Create financial support mechanisms to make investments attractive to developers. *Protect marine ecosystem through licensing procedures based on site-specific environmental studies that guarantee implementation of an environmental monitoring system in the designated marine areas for MUPS development. *Involve different stakeholders who can share and improve their knowledge, influence MUPS developments, and together search for creative solutions to difficulties in development and implementation of MUPS.
Governance and planning policy in the marine environment for regulating aquaculture in Scotland (Peel and Lloyd, 2008)	Changing state–market–civil relations involved in evolution from a nonstatutory to a statutory planning regulatory regime for marine aquaculture in Scotland; state interventions to correct the perceived market failures associated with aquaculture and its environment.	*Design an appropriate form of governance that is open, participative, accountable, coherent and effective. *There is need to conduct more research to inform the emerging marine environmental planning and governance debates.

Policy analysis/studies	**Policy issues/problems**	**Recommended policy solutions**
Institutions-based analysis approach to assess policy design and interpretation of aquaculture policies in Florida and Virginia of the United States (Siddiki, 2014).	Understanding the design of policies governing the behavior of aquaculture participants in Florida and Virginia; understanding the relationship between perceptions of policy legitimacy, coerciveness, and enforcement in shaping individuals' interpretations of regulations	Better knowledge of policy interpretation can assist both the policy scholar and practitioner in homing in on the particular aspects of policies that are likely to be met with most resistance and be least effective.
Impact of Europe's coastal fisheries policy (Symes et al., 2015)	Increasing stress from both internal and external pressures for change; growing instability and uncertainty affecting Europe's coastal fisheries and fishing communities; tensions between and within the current sectoral and territorial approaches to management; understanding recent moves to find a middle way that can contribute more effectively to resilience building	Devolve much of the responsibility for managing coastal fisheries to the local and regional level where the nature of the interactions between the ecological and social subsystems are more readily apparent, the issues arising more sharply defined, and the opportunities for interactive governance and resilience building more readily realized.
Policy analysis for tropical marine reserves: Challenges and directions (Rudd et al., 2003)	Understanding use of marine reserves as a central tool for marine ecosystem-based management in tropical inshore fisheries; lack of rigorous policy analyses that consider a full range of economic costs and benefits, including transaction costs of management	Determine the proper balance of the state and the community in tropical fisheries governance through broad comparative studies of marine reserves and alternative policy tools.
Demand for improved fish feed in the presence of a subsidy: A double hurdle application in Kenya (Amankwah et al., 2016)	Determining demand for improved fish feed from private markets, and whether the government feed subsidy program affects private demand for improved feed	Policies that help reduce the price of improved feed such as reduction in tariffs on imported feeds and feed ingredients will foster demand for the feed, as will policies that facilitate marketing of fish at reasonable prices by households.
Rights and representation support justice across aquatic food systems (Hicks et al., 2022)	Understanding whether barriers to participation explain unequal distributions of benefits in AqFS	Injustices are prevalent in food systems, where the accumulation of vast wealth is possible for a few, yet one in ten people remain hungry. Results show that countries produce and consume less when wealth, formal education and voice and accountability are lacking. Aquatic foods are less affordable where gender inequality is greater. The policy analysis reveals a frequent failure of national policies to address political and gender-based barriers to more just food system outcomes centered on principles of human rights.

Policy analysis/studies	Policy issues/problems	Recommended policy solutions
Fishing for health: Do the world's national policies for fisheries and aquaculture align with those for nutrition? (Koehn et al., 2022)	Determining if fisheries and aquaculture policies have explicit nutrition and public health objectives and if public health nutrition policies recognize the contribution of aquatic foods	More targeted and systematic policy approaches are needed to realize the potential contribution of nutrient-rich fish and shellfish to healthier food systems.
Rapid policy network mapping: A new method for understanding governance structures for implementation of marine environmental policy (Bainbridge et al., 2011)	Numerous potential conflicting objectives both within and between nations	Future policies to implement environmental assessment might focus on setting goals and targets at the more local level, with a stakeholder led process propagating from local spatial scales upward toward a unified European vision and legal formalization. Using the collaborative features inherent in rapid policy network mapping, stakeholders could discuss and identify means of improving democratic accountability, policy efficiency, and innovative institutional structures.

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