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A Scenario Tool for Sustainability Transformation in Fisheries and Beyond

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ABSTRACT

The urgency to find sustainable management solutions intensifies with increasing natural resource scarcity. Resource sectors are usually characterized by diverse resource users. We developed a structured scenario tool designed to quantitatively assess policy options for achieving sustainability, accounting for ecological, economic and institutional boundaries. Parameterized with stakeholders' input, the tool is exemplified for the German Western Baltic fishery, a sector under pressure from collapsing fish stocks and often regarded as “time machine.” It fits the structure of many resource sectors with different user types, often few large and many small-scale users. We evaluate two ecological scenarios in combination with four governance approaches against the economic viability of different fishery types. Under low biological productivity, the current quota allocation is not economically viable for most fishery types, highlighting how environmental crises lead to human crises. While large-scale fisheries stay unsustainable in the Western Baltic, a quota redistribution could pave the way for viable small-scale fisheries. The tool illustrates interrelations between boundaries to support evidence-based policy-making for sustainability transformations in fisheries, but also for allocations of land use, emissions or water rights. It also illustrates the role of firms' cost structures for economic viability when ecological boundaries require reduced natural resource use and how institutional settings can support a sustainable natural resource sector.

1 | Introduction

The urgency to find sustainable solutions intensifies with increasing natural resource scarcity, as their dwindling stocks threaten the well-being of current and future generations. Sustainable development has been operationalized with the help of the Sustainable Development Goals (SDGs). Using the planetary boundary conditions to reflect bio-physical limits (Rockström et al. 2009; Richardson et al. 2023) and adding the human needs as a foundation for social well-being leads to a ‘doughnut’ model (Raworth 2012; Vince 2012). The model sets a safe and just space within which humanity can operate, especially given trade-offs in achieving the different SDGs (Riekhof et al. 2019). A remaining challenge relates to applying this concept at the local level with a focus on governance (Turner and Wills 2022).

We build on the viability approach (e.g., Béné et al. 2001; Schaber et al. 2022) that has been used to define local boundary conditions and then develop a novel scenario tool to explore how different policy options perform under given ecological, economic, and institutional boundary conditions. Since institutional settings are closely tied to societal aspects, the tool represents all three sustainability dimensions (Purvis et al. 2019; UN 2012) and it addresses the need of quantitative data being available in a structured and easily accessible way. The novel tool suggests a straight forward way to organize information. It can be used to quantitatively explore different future ecological scenarios and determine how the distribution of resource use opportunities impact the economic viability of various user types. "Quantitative exploration" relates to the exploration of different what-if scenarios in a numerical way with parameter values to match a given situation. It does neither imply statistical estimation nor forecasting. The tool can thus support and guide transformation processes within a given sector, for example, related to the calls for sustainable and resilient food systems (UNDP 2025; EU 2025).

To illustrate the value and utility of our scenario tool to guide transformation, we chose the case of the German Western Baltic fishery (WBF). The Baltic Sea is characterized as "time machine" related to impacts from climate change and other antropogenic pressures (Reusch et al. 2018), making it a perfect test case for the tool's applicability for resource systems under pressure that need transformation. As a marine example, it also aligns with the current ocean decade "the science we need for the ocean we want" (https://oceandecade.org/). In addition, its structure with few large and many smaller firms, often even having resource income as side-income, is typical for resource sectors around the world (see SI 6).

The German WBF has been undergoing structural change for several years due to changed ecological (Möllmann et al. 2021; Polte et al. 2021; Scotti et al. 2022) and socio-economic boundary conditions (de Graaf et al. 2023; Lewin et al. 2023). Cod (*Gadus morhua*) and herring (*Clupea harengus*) as the traditional key target species for the fishery showed a strong decline in stock size, caused by a combination of anthropogenic pressures such as overfishing and climate change (Möllmann et al. 2021; Froese et al. 2022) and inappropriate institutional settings (Froese et al. 2025). Future trajectories in fish stocks development under climate change are highly uncertain (Voss and Quaas 2022; Conradt et al. 2024). Accordingly, the fishery needs to adapt to changing system conditions. Societal preferences in favor of many (smaller) resource harvesters and for a balance between different interests have been documented by transdisciplinary processes (BMEL 2023; Schaber et al. 2022). At the same time, we see that in many countries, the share of large vessels (> 60 m) increases, while the general vessel number declines (Riekhof and Noack 2024). Although several measures have been proposed to achieve the goal of preserving small-scale fisheries (e.g., BMEL 2023; Barz et al. 2025), it is still an open question what the desired outcome and the suggested policy measures imply in a quantitative manner, that is, how does a redistribution of catch possibilities between different types of fishery businesses and measures, like increasing market prices or reducing costs, translate to changes in the structure of the German WBF and the number of resulting fishery businesses, given ecological and economic constraints.

In this paper, we first develop and parameterize a scenario tool that allows to explore different structures of a natural resource sector, that is, the numbers of different business types sustained by ecological, economic and institutional conditions, and policies needed to reach a sustainable outcome. The structured approach to organize data can be applied to other natural resource sectors to guide sustainability transformation. For the German WBF, we aggregate the diverse fisheries into four types and characterize their economic key figures using various sources combined with local fishers' knowledge. We then apply the tool to quantify the economic performance of the different fishery types under current ecological-institutioal conditions, with institutional conditions relating to the currently implemented quota distribution. Finally, we explore potential future outcomes under different ecological boundary conditions in combination with quota re-distribution to steer transformation. Our analysis shows that ecological boundaries (i.e., stock productivity) and economic boundaries (alternative income opportunities) determine which institutional settings (i.e., quota re-distribution options) might pave the way for a viable future fishery. Under current and most probably continued low biological productivity, the current quota allocation will not lead to economic viability of most fishery types, illustrating how environmental crisis can lead to human crisis. Especially the large-scale fishery using trawl gear will not achieve economic viability—even if all quota would be concentrated on this fleet type. Institutional and societal change related to quota re-distribution could contribute to reach viable small-scale fisheries. Our case study has demonstrated how the scenario tool can support evidence-based policy-making to guide a sustainability transformation of natural resource sectors taking natural limits and well-being into account by working with ecological, economic and institutional boundary conditions. To highlight, the scenario tool is not only applicable to fisheries, but can easily be adapted to all types of resource sectors, especially when focusing on the distribution of use rights such as for water or emissions.

2 | Results

2.1 | One Tool to Rule Them All

Our scenario tool allows us to quantitatively explore the effects of changes in ecological, economic, and institutional boundary conditions on the sustainability of future configurations of a resource sector (Figure 1). The tool is meant for resource sectors with the allocation of use rights as its major governance instrument or when the impact from other policy instruments conditional on use or access rights to the resource is of interest. As a base, resource users are grouped into different types according to characteristics relevant for the specific situation. The tool is parametrized for these groups. Then, boundary conditions are set. As an ecological boundary condition, the user can set different future developments of the resource stocks. In our case, the user can set whether future developments of the target fish stocks are linkely stagnant or positive (see Table S8 in SI 4). The tool presents the institutional boundary condition in terms of the total quantity of allowed resource use and how the use opportunities are distributed. In our case, it relates to the total allowable catch (TAC) and how the fishery quotas are distributed between different fishery types of the German fleet operating in the Western Baltic. As an economic boundary condition and to reflect economic viability, a monthly reference income can be specified that reflects the viability of the business for the owner, which is subsequently compared to the realized resource income. The tool furthermore offers the possibility to deviate from the default settings for the resource user types on prices and costs to simulate differentiated subsidies or marketing measures to increase prices. We termed the application of the scenario tool to the Western Baltic Fishery "Fisheries Transformation Tool

(FiTT)". It is available at https://ceos.shinyapps.io/ScenarioToolBalticSeaFishery/ (see SI 5 for further information).

Fishery types, which encompass all segments of the German Baltic fleet, are derived by grouping businesses based on number and types of vessels, fishing gears used, ways of marketing related to the degree of organization, and income share derived from fishing (Figure 2, SI 1 for details). Fishery types furthermore range from full-time, organized businesses with larger trawlers (Type A) to part-time, non-organized coastal fishers, operating locally with small boats <8 m (Type D). Default costs and prices of each fishery type have been defined taking into account fixed and variable costs as well as differences in marketing strategy (Figure 3, SI 3 for details) and in exchange with fishers to take advantage of practitioners' knowledge (Hartig-Thiemann 2025).

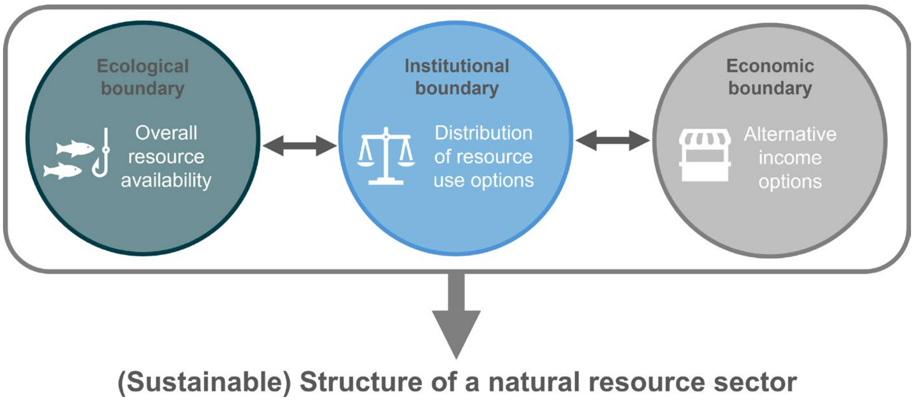

FIGURE 1 | Illustration of the framework of the scenario tool to assist the development of a sustainable natural resource sector. Three interrelated boundary conditions have been considered: Overall resource availability (ecological), distribution of resource use possibilities (institutional), and alternative income options for firms (economic). The general boundary logic of the tool is generic (While natural productivity may be enhanced, for example, with fertilizers or adding feed, there is still a limit at some point. It is similar at the economic side: while cultural aspects or preferences may keep people in a certain job although they may earn more somewhere else, there is eventually a boundary related to being able to cover basic needs. What is most specific to a sector is the institutional boundary condition, that is, how are natural resources or the use opportunities allocated. This may be related for example, to space or directly to the resource). The application of the tool to a certain resource sector needs specification along three lines. First, the boundary conditions need to be quantified. Second, the user types need to be delineated. While large, small, and part-time firms are quite common (see Table S9 in SI 6), certain sectors and research questions may warrant different clustering. Last, the production and profit functions need to be determined. Next to parameter values, a production function may have to be developed that translates the resource into the product sold on the market if both are not identical (see SI 6 for examples).

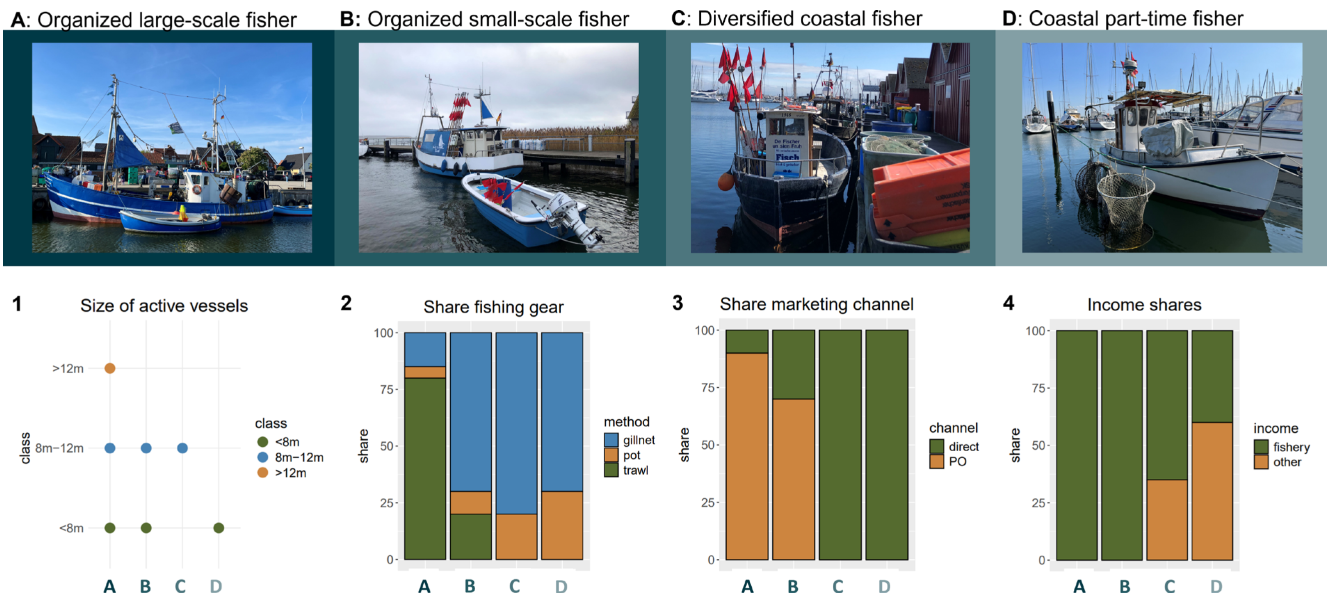

FIGURE 2 | Charaterization of fisheries businesses types in the German Baltic Sea fisheries. The fisheries businesses are classified on the basis of several characteristics into four types: Type A (the organized large-scale fisher, dark petrol blue), Type B (the organized small-scale fisher, petrol blue), Type C (the diversified coastal fisher, light petrol blue), Type D (the coastal part-time fisher, gray blue). Characteristics encompass size and number of vessels (1), fishing gear (2), marketing channel related to degree of organization (3), income shares from fisheries (4). (PO = producer organization, for organized businesses) H. Schwermer for the pictures.

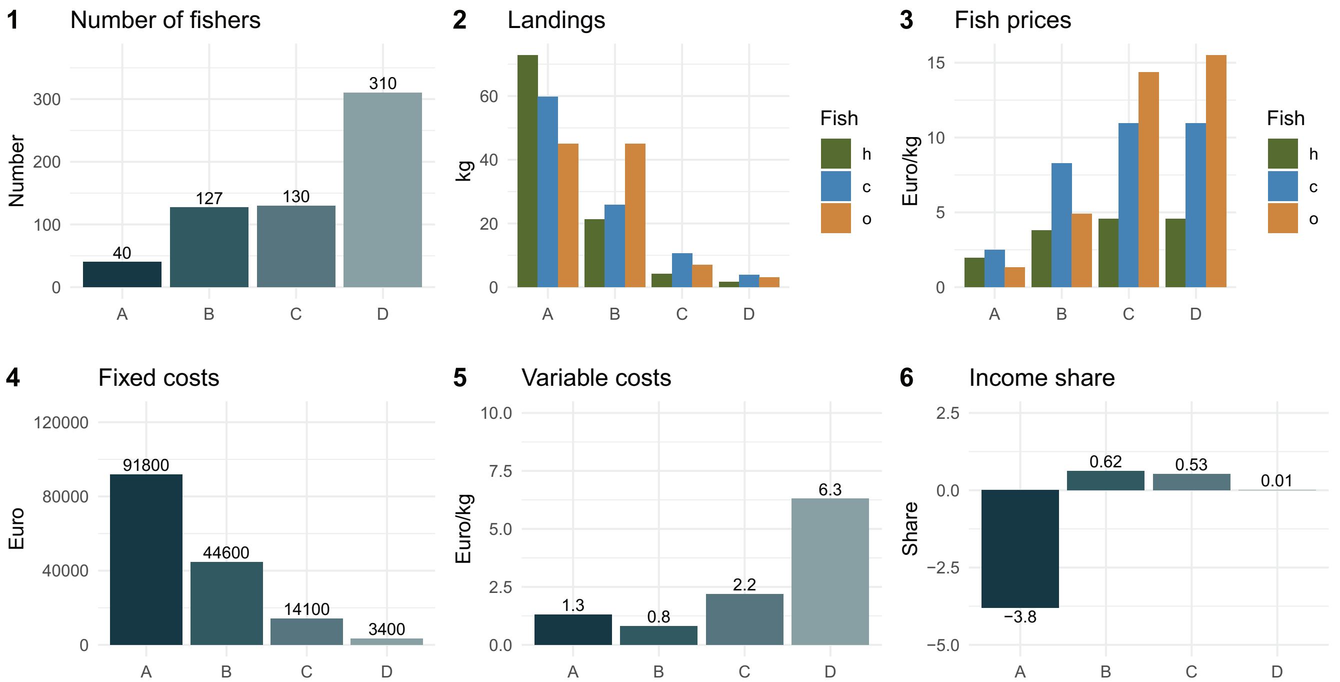

FIGURE 3 | Calculated parameters and resulting income shares for the four business types under present ecological, economic, and governance conditions. The letters refer to the different business types: Type A (the organized large-scale fisher, dark petrol blue), Type B (the organized small-scale fisher, petrol blue), Type C (the diversified coastal fisher, light petrol blue), Type D (the coastal part-time fisher, gray blue); and to fish species: h = herring, c = cod, o = other. Ecological conditions as of 2022 relate to possible landing amounts of herring, cod, and others of 166, 35, and 4000 t/y, respectively. (t = tons, y = year). Number of fishers (1) relates to numbers of businesses in that type. The calculated distribution of German landing possibilities across fishery types leads to landings depicted in (2). Prices (3) are calculated based on targeted species and marketing channel. Fixed costs (4) are per firm per year, variable costs (5) are per kg of fish caught. Details on the parameter calculations are given in SI 3. Income shares (6) relate resulting incomes from fishing to a reference income (here: 1944 €/month). A negative number implies a loss, here for Type A of the size 3.8*reference income.

2.2 | No Economically Sustainable Fishery Under Present Conditions

We first applied the tool to explore the potential of the fishery to be sustainable under present ecological, economic, and institutional conditions, and given the current number of fishery business (see Figure 3 [1]). Our data assemblage shows that the larger scale, full-time, organized fishery (Type A) has a considerably higher share in herring and cod quota and resulting landings than all other businesses (see Figure 3 [2]). Type A and B generate lower prices per kilo of fish caught compared to Type C and D (see Figure 3 [3]), who market the fish directly (see Figure 2). By marketing all fish directly, Type C and D do not only obtain higher prices, but also contribute to the revitalization of an active port, which supporting the cultural value of fishing. Especially Type A faces higher fixed costs related to harvesting (see Figure 3 [4]): due to the size of the fishing vessel, for example, two additional persons are employed (personnel costs are a major cost item) and additional equipment must be carried on board and maintained (e.g., vessel monitoring system [VMS]). However, Type A can react quickly to a stock recovery and can fish larger quantities due to its large vessels. Towing the fishing gear results in significantly higher fuel consumption causing comparatively higher variable costs of Type A as compared to Type B (see Figure 3 [5]). Type D has the highest variable costs due to no access to fuel subsidies and comparably low amounts of catches. The values depicted in Figure 3 [1–5] can be varied in the scenario tool.

To explore the sustainability of the current fisheries, we consider the overall catch possibilities in 2022, just before both fisheries were closed for directed fisheries (EU 2022, 2023a). For cod, the Total Allowable Catch (TAC) was 489 t, the actual estimated commercial landings were 136 t (ICES 2023a). For herring, the TAC was 788 t, while the landings were 638 t (ICES 2023b). We include these landings into the tool to represent catch possibilities. Then, calculations with the tool show that income of Type A turns negative (Figure 3 [6]). This is in line with reports by the EU on losses for the larger businesses in the fishery sector (STECF 2024). Type B can obtain only 62% and Type C only 53% of the reference income (net income that a person with the training of a fisher could earn on the job market: 1944 €/month after tax; see SI 4). In many cases subsidies, for exmple, payments for the temporary cessation of cod fishing activities in the Baltic Sea, reduce the losses and keep the fishers from leaving the sector in the short run (BMEL 2024). Type D, the part-time fisher, is basically able to cover costs, not generating any profit (see Figure 3 [6]). The present exploration shows that there is no sustainable fishery possible under current ecological, economic, and institutional conditions.

2.3 | Quota Re-Distribution to Achieve Future Sustainability?

One way to achieve future sustainability for a given resource productivity is the allocation of individual harvesting possibilities, that is, changing the related institutional boundary condition. We hence explore whether top-down quota re-distribution between fishery types (which is in principle possible under German law) could contribute to achieve future economic viability of the fisheries under different ecological boundary conditions (stagnant and positive), based on output of stock projections with different assumptions on severity of climate change impacts. For both resource productivity options, we compared the outcome of four scenarios of resource allocation for the year 2035, specifically we compared (i) the current quota distribution between fisheries types to (ii) a concentration of quota on the larger businesses (Type A), (iii) a ban of trawling (no quota for Type A), and (iv) a focus on small-scale fishing to increase the presence of fishery along the coast and to preserve its cultural value (all quota from A and B given to C).

Assuming a positive future stock development of cod and herring until 2035 would strongly improve the economic prospects. Under "Status quo" quota distribution, fishery Types A, B, and C would generate higher profits than the reference income (Figure 4, upper row). Quota re-allocation schemes may result in high profits for specific fishery types ranging from about 4 times the reference income ("Few large firms," Type A) to about 8 times the reference income ("Cultural importance," Type C). In contrast, under the assumption of stagnating cod and herring stock development (constant other catch opportunities), which is the most probable scenario, the "Status quo" quota distribution would not sustain any fishery in its current form (Figure 4, lower row), not even Type C with a reference income share of around 65% from fishing (see Figure 2). Without changing the allocation of harvesting possibilities, the most probable outcome to achieve economic viability would be a further decrease in the number of fishing businesses. Type A is especially sensitive to a stagnating stock development: even when concentrating all available cod and herring quota on this professional large-scale part of the sector (scenario: "Few large firms"), it would still generate negative profits. Types B and C are relatively robust to different quota allocation schemes in the sense that incomes do not turn negative. This can be explained by the ability to target the group of "other" resources, like sprat, eel, or plaice, species for which we do not assume any re-allocation of catches. Still, only the scenarios "Ban of trawling" or focusing on "Cultural importance" would allow for incomes higher than the set reference income

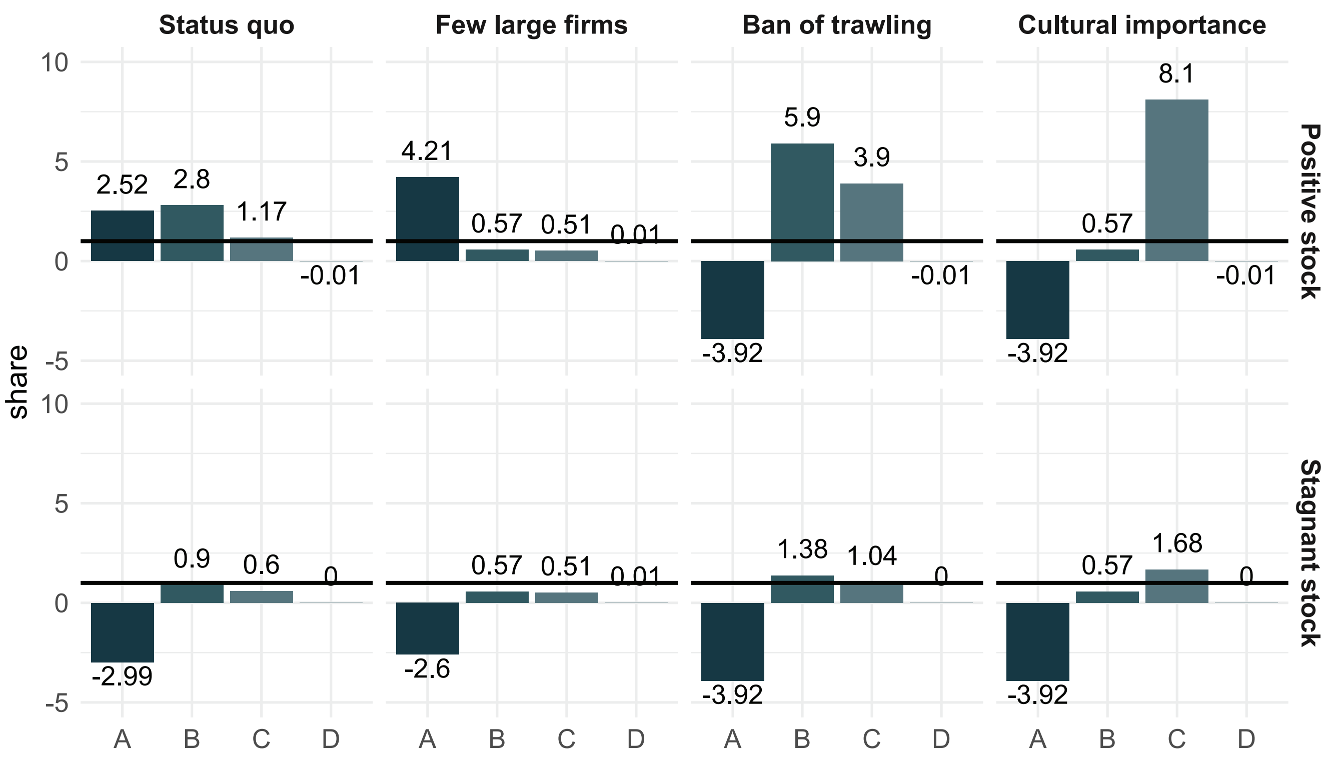

FIGURE 4 | Fishery income relative to the reference income for different quota allocation scenarios for the four identified fishery types for the year 2035. Scenarios are described in the Section 4. Results are displayed both for positive and stagnant stock developments (upper and lower row, respectively). The black line is at 1 to indicate when the reference income is reached. The letters refer to the different business types: Type A (the organized large-scale fisher, dark petrol blue), Type B (the organized small-scale fisher, petrol blue), Type C (the diversified coastal fisher, light petrol blue), Type D (the coastal part-time fisher, gray blue). Type C and Type D aim to reach 65% and 40% of the reference income by fishing. The figure illustrates that there is no quota allocation scheme in which the economic boundary condition is met for all business types. Next, we asked how many businesses of a certain fishery type could be sustained under different quota distribution scenarios, given we assume that each earns the reference income (or in case of Type C and D 65% and 40% of this income, respectively). In this case, Type A could not sustain any businesses under "Ban of trawling" and "Cultural importance," but 61 (7) and 86 (10) under "Status quo" and "Few large firms" under positive (stagnant) stock development (Figure 5). The number of businesses of Type B would vary between 102 and 501 (under "Ban of trawling" and positive stock development). Type C would show the largest variation in businesses that could be sustained under the different scenarios, between 112 (under "Few large firms," independent of the stock development) and 1549 businesses (under "Cultural importance" and positive stock development). The number of part-time fishers (Type D) is relatively stable around 80, and relatively independent from stock status and scenario.

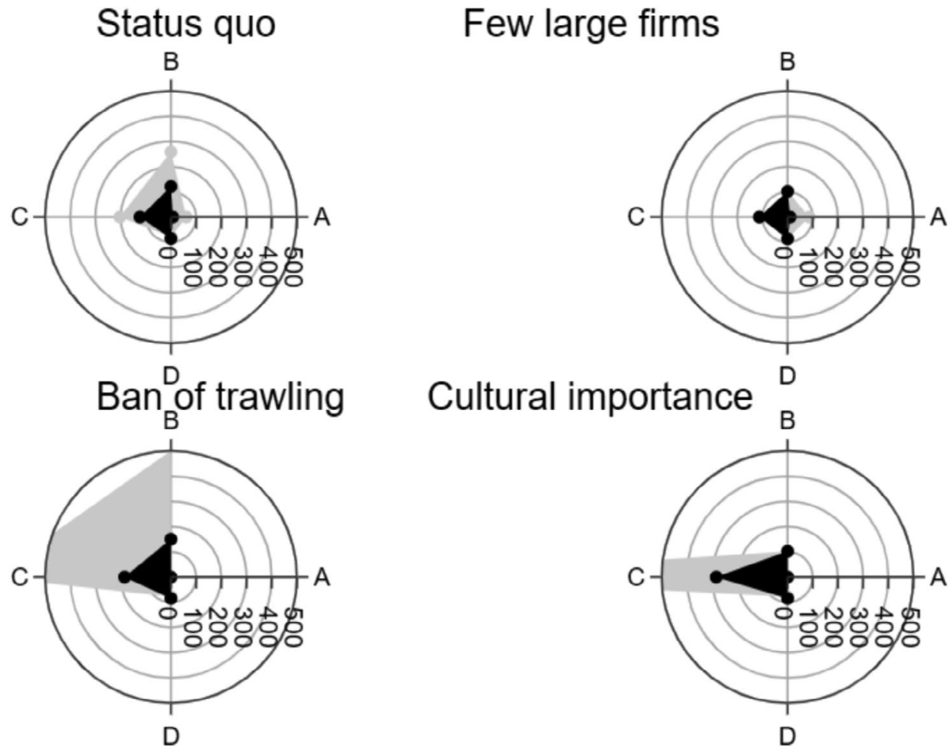

FIGURE 5 | Number of firms that can be sustained when the reference income is earned. For Types A and B, the references income is a net income of 1944 €/month; for Types C and D 65% and 40% of this income, respectively. The black dots/shaded areas show outcomes under stagnant stock conditions; the gray dots/shaded ares show outcomes under positive stock developments. The figure illustrates that the number of firms in a given fishery type strongly depends on quota allocation and the ecological conditions.

in Types B and C or only in C, respectively (Figure 4). The currently prevailing stagnating stock development would therefore call for governance action and for a change in the institutional boundary condition—that is, re-distributing quota in terms of a higher share to smaller-scale fishery businesses (Types B and/or C). Under all scenarios, the part-time fisher (Type D), can more or less cover its costs.

3 | Discussion

3.1 | The Need to Include Interlinked Boundary Conditions and Data on Small-Scale Resource Users

With our scenario tool, we contribute to the discussion on sustainability transformations in social-ecological systems by highlighting distributional questions related to the depletion of natural resources and the interplay between ecological conditions, market forces and institutional settings in shaping the structure of the sector. In particular, we are developing a straightforward approach to quantitatively combine ideas on how a future resource sector may be configurated and necessary measures to achieve this. In addition, our application of the model to the German Western Baltic Sea fishery showed also the need for economic (and not only ecological) data being available. We tried to fill a data gap to make relevant analysis possible. Especially, we present an analysis that also includes the small-scale sector that is often excluded from reports (e.g., test operating network of the German fisheries (BMEL 2022)). Its inclusion allows examining the impact of new policies, for example, the new control regulation by the EU (2023b) that states that smaller vessels now also need satellite-based vessel monitoring systems (VMS), which means an increase in costs. While better monitoring is warranted for sustainable resource use (Riekhof and Noack 2024), its costs should be taken into account. Overall, to steer the sector into a sustainable future the entire sector must be considered, which also requires better access to socio-economic data of the fisheries. Related, socio-economic data should also be included in the development of an EBFM approach (e.g., Scotti et al. 2022).

3.2 | Contributing to Policy Implementation in the Western Baltic Sea Fishery

In our example, the German Western Baltic Sea fishery, most of the quota is currently distributed to larger businesses, with an increasing trend in quota concentration as reflected in the scenario "Few large firms". However, the tendency to concentrate quota on the larger businesses with bigger vessels is not necessarily viable. Our results show that Type A is highly dependent on fish stock developments due to large fixed costs, for example, for employees. With positive stock developments, this business type could generate high profits, whereas with stagnant fish stock developments, losses will be generated. Since fish stocks in the Western Baltic Sea need to be rebuilt to support an economically viable fishery and stock recovery being uncertain (Möllmann et al. 2021; Scotti et al. 2022), allocating quota only to large fishing businesses is highly unsustainable, unless one aims to foster the option of firms to switch between the Baltic and other regions (e.g., the North Sea). Presetly, a complete ban of the trawl fishery in the Western Baltic Sea is discussed, taking into account ecological considerations (scenario “Ban of trawling”), that is, the reduction of negative exteranlities on the ecosystem. Alternatively, various stakeholder groups, such as eNGOs and small-scale fisheries, have been increasingly demanding for the introduction of quota allocation with a stronger focus on artisanal fishing techniques, cultural values, and tourist attraction (EU 2013; LIFE 2023; Oostdijk and Elsler 2024) (scenario “Cultural importance”). This aspect is also reflected in various works by the German government, for example, a commission on the future of the German fisheries convened in 2023 (BMEL 2023).

While Types B and C can deal better with a stagnant stock development, allocating all quota from Type A to B and/or C may pose difficulties when fish stocks strongly increase under very positive stock development. Direct-marketing of such a large amount may be unrealistic, and it is unclear, whether fishery Types B and C (without Type A) could actually technically fish all quota under a very positive stock development. Future stock developments and resulting catch possibilities for the German Baltic Sea fishery have been discussed (e.g., Scotti et al. 2022; Möllmann et al. 2021), but without a differentiation of various fleet segments, that is, fishery business types. Thus, our tool can strongly contribute to political discussions on the future transformation of the fisheries sector toward a resilient and sustainable future.

3.3 | Sustainability: Can It Be Achieved Along Its Three Dimensions?

Comparing the different quota allocation schemes, several observations on the dimensions of sustainability, including distributional impacts, can be made. First, all quota allocation schemes meet ecological sustainability, as the total allowable catch stays the same and is set in line with sustainability criteria. Focusing on the ecological sustainability of certain fishing gear can favor different quota allocation schemes, most likely those that reduce trawling, that is, “Ban of trawling” and “Cultural importance.” Second, economic sustainability—in the sense of meeting the economic boundary condition—strongly depends on the number of firms and the quota allocation. Keeping the number of firms fixed, economic sustainability is rarely met (see Figure 4). Third, for societal sustainability, we discuss three different operationalization: one relates to a certain equality in income distribution, another to a high number of firms as being related to a high number of jobs, and a third one relates to changes with respect to the status quo. Equal incomes would be achieved by changing the numbers of firms, as explored in Figure 5. As this highly depends on the (uncertain) ecological status of the fish stock, we focus our discussion on comparing the quota allocation schemes for a given number of firms. It turns out that the “status quo” and “few large firms” lead to lower equality, but they do not meet the economic boundary condition for many firms. For a higher number of jobs, allocating quota based on “ban of trawling” or “cultural importance” in addition with allowing for changes in the number of firms would be optimal. Both imply quite some re-distribution related to the status quo, from the firms of Type A to the firms of Type B and C. The challenge to achieve societal sustainability and at the same time meeting ecological and economic boundary conditions, becomes apparent.

3.4 | Robustness of Results: From Data Validation to Sensitivity Analysis

In data scarce situation, the compilation and validation of information is a challenge. To determine the tool's parameter values to reflect the German Western Baltic Sea fishery, we used official statistics whenever available, for example, related to prices. If official data was not available, we usually crossed-checked information at least with two independent sources, for example, for costs related to mooring, we took the mean value of different ports (e.g., GWH 2021) and also talked to personal contacts. Details are given in the Supporting Information. In many instances, we checked with local fishers. A first test of the combination of parameter values came by looking at economic theory related to incomes: for reasonable values, incomes should be positive, or only negative for obvious reasons. Thus, we relied on structural consistency with economic theory, alignment with reported economic outcomes and official statistics, and stakeholder information for parameterization and validation.

The tool allows for individual sensitivity analysis for the Baltic fishery case. Users themselves can explore “what-if” scenarios in the web-based shiny-R application, especially related to prices, costs, quota allocation, and reference incomes.

Key uncertainties in the Baltic Sea fishery relate to fish stock developments, especially under climate change and other anthropogenic pressures. For this reason, we included two (with the current status even three) potential developments of the cod and the herring stock to illustrate whether and how this would impact results, that is, incomes of the different fishery types under the examined quota allocation. One driver of results is also the development of “other stocks,” which is neither changed in the two ecological scenarios nor by changes in the general quota distribution. Different fishery types target different fish species, resulting in different prices for “other.” Some—especially Type B and C, obtain a relevant income from these sources, which makes them robust to different quota allocation schemes and changes in the development of cod and herring stock. A more detailed analysis, including the occurrence of new species, could be an avenue for further research.

3.5 | Shortcomings: The Need for Manual Adjustments

While the tool allows to easily explore different scenarios, it is static in nature. It does not directly take intertemporal effects into account—only via different scenarios. In addition, it does not include a constraint on capacity per business. For large catch amounts, fixed costs may rise and then would have to be adapted manually. Further, the tool does not include externalities, for example, unintended (negative) effects on the environment, although these can be explored through various scenarios (see our scenario "Ban of trawling"). While we think that the different types reflect the fishery segments of the Baltic fishery quite well, it remains a simplified consideration of the diverse German Baltic Sea fishery. Meyer and Krumme (2021), for example, identify eight distinguishable groups within the German Baltic gillnet fishery alone. In general, the tool's flexibility allows to form other groups as the base for analysis. Lastly, it should be noted that we are using averages to calculate the different values for Types A–D. For example, the average price of Type A for "Others" is so low that it covers variable costs, and accordingly, cannot contribute to covering fixed costs. For Type D, the cost per kg fish is higher than the price for kg herring, such that a positive quota share for that type leads to losses. These outcomes result from grouping diverse businesses into four types. It shows that with different scenarios, also the parameters may need adaptation to mirror the reaction of the businesses.

3.6 | Application: From Stakeholder Engagement Over Exploring Other Policies to New Case Studies

While we present first explorations of different scenarios of the Western Baltic fisheries, the tool is published as open access allowing the application to other resource sectors as well as the exploration of further Baltic Sea fishery scenarios. The tool is generally easy to understand and follow, enabling the application by scientist of different disciplines or by stakeholders, for example, to examine their own envisioned structures for the resource sector being considered (Schaber et al. 2022). Next to quota re-distribution, the tool also allows to examine how policies that increase prices or reduce costs impact the viability of envisioned sectoral structures (in terms of numbers of businesses per type). Furthermore, application cases can relate to interpreting the reference income as target income—that is, what resource users ought to earn, and examine change needed to reach that level. Sustainability transformation and for example, the question of distributing production possibilities and how it impacts sectoral outcomes is also relevant in farming. Worldwide, small farms (< 2 ha) make up 84% of all farms worldwide, operate around 12% of all agricultural land, and produce about 35% of the world's food, while the largest 1% operate more than 70% of the world's farmland (Lowder et al. 2021). As economies grow, the sector also experiences concentration of farmland among large farms (Lowder et al. 2021). Related questions also impact the question of allocating water use rights and whether the institutional setting may need to be adapted with ongoing climate change (Gómez-Limón et al. 2021). For the tool to be applicable to cases in which the resource use opportunity does not refer to the product itself (like in the case of fish), the production equation in the background needs to be adapted to translate resource use decisions into the product sold, but the general logic remains the same.

4 | Methods

4.1 | Scenario-Tool Framework

Whether resource users stay in or leave a resource sector is related to their outside income opportunities. While most people are willing to sacrifice some income for a job they love and identify with, they still have to make a living. Incomes in the resource sector are bounded by the productivity of the natural resource stock (Noack et al. 2018) and to a large extent determined by the harvesting opportunities, often in form of land or a quota. Thus, the availability of overall harvesting opportunities (i.e., for the whole sector) determined by ecological conditions, the allocation of individual harvesting opportunities determined by the prevailing institutional setting, as well as a reference income determined by the economic boundary condition (i.e., when a resource user would decide to leave the resource sector) are three boundary conditions for discussing the structure of the resource sector and the number of remaining resource harvesters.

The boundary conditions also determine the structure of the scenario tool. First, the future resource productivity has to be considered. For the Western Baltic Sea, we consider the economically important species cod and herring explicitly, and lump all other species together in "other." Based on the stocks, total German catch possibilities are determined, which can then be distributed to different fishers (institutional boundary condition). To consider the structure of the resource sector, we cluster businesses into a few types as given in Figure 2 (see below for details).

The income of a business in the resource sector is calculated as revenue minus expenditure (see SI 2 for details). Revenue is the price multiplied by the quantity sold. Expenses can be roughly divided into variable and fixed costs. For our model, we distinguish between costs that occur once per business and year (here: e.g., mooring fees) and costs that are dependent on the quantity produced, here of fish caught. Prices and costs can differ between the business types, depending for example, on their marketing strategy and gear used. Details can be described qualitatively and adjusted quantitatively in the scenario tool. Figure 3 [2–5] illustrates these additional parameters that determine income and thus also influence the structure of the resource sector.

Resulting income per business—especially given the allocated catch opportunities and the envisioned number of businesses by type—is compared with the reference income (see SI 4 for details). Here we compare net incomes such that we also have to subtract taxes. If individual net fishing income is below the reference income, the fisher has to obtain an income from other sources.

4.2 | Clustering of Fishery Business Types

Due to the data poor environment, we could not apply an algorithm-based clustering. Also, we had to strike a balance between representing the diversity in the sector and keeping the model tractable, especially as the scenario-tool allows to specify many details around prices and costs, differentiated according to fish species and business types. Thus, we cluster the fishery businesses into four different types based on the four categories that are often used to discuss the German Baltic Sea fleet, namely (a) vessel length, (b) fishing gear, (c) type of business (main vs. side business), that is, income share from fishery, and (d) degree of organization and related, marketing options (Figure 2, more information on these categories in SI 1).

4.3 | Data Collection and Calculation of Parameters

We obtain biological information from International Council for the Exploration of the Sea (ICES) Working Group reports (ICES 2022a, 2022b). Scenarios of future catch potential for cod and herring are derived from an updated ecological-economic multispecies model tailored to the Western Baltic Sea (Voss et al. 2022; Voss et al. 2026). The positive scenario assumes no impact of climate warming on stock productivity and a (partial) stock recovery following optimal management. The stagnation scenario accounts for imperfect management as well as a negative effect of climate change on both stocks (Scotti et al. 2022; Polte et al. 2021; Voss et al. 2019). For economic numbers, we conducted a literature review, a comprehensive web study (e.g., direct marketing prices, operating costs), information taken from our own previous work on fisheries in the Western Baltic Sea (Schwermer et al. 2021; Möllmann et al. 2021; de Graaf et al. 2023), and the active involvement of stakeholders (e.g., sharing business documents). We then calculated values for the different parameters differentiated according to fishery type based on their characteristics (see above). All data and other relevant background information are given in SI 3. The scenario tool, which we termed "Fisheries Transformation Tool—*A Scenario Calculator to assist Structural Change*" is programmed in shiny R and available at https://ceos.shinyapps.io/ScenarioToolBalticSeaFishery/ (SI 5).

4.4 | Definition and Analysis of Scenarios

The "Status quo" scenario keeps the current quota distribution while "Few large firms" concentrates all quota on Type A. In this scenario, the fishery will be easy to monitor and control, with nearly perfect catch data. The "Ban of trawl fishery" due to environmental concerns and to protect the sea bed and in line with the Article 17 of EU (2013) implies no quota for Type A. This quota will be distributed across Type B and C, proportional to existing firms (leading to herring quota of 78% [Type B] and 20% [Type C]; and cod quota of 72% [Type B] and 24% [Type C]). In the "Cultural (and touristic) importance" fishery, all quota from A and B will be given to Type C with the idea of a fishery distributed along the coast. In each case, we compare income with the given number of firms in the considered type as well as how many firms would be sustained if the reference income is earned (65% and 40% of this income in the case of Type C and D, respectively). We consider both cases, stagnating and positive developments related to fish stocks.

4.5 | Coding

Calculations were done in R, using large language models for support in creating figures.

Author Contributions

Conceptualization: M.-C.R., H.S. Methodology: M.-C.R. Investigation: M.-C.R. H.S. Writing – original draft: M.-C.R. Resources: T.H.-T., H.S. Data curation: T.H.-T., H.S. Writing – review and editing: T.H.-T., H.S., R.V., C.M., L.T. Formal analysis: T.H.-T. Software: L.T. Visualization: M.-C.R., H.S. Funding: M.-C.R., C.M.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Quota distribution for cod and herring to different fishery types (BLE 2019, 2020, 2021a, 2022a). **Table S2:** Quota allocation cod and herring for type A and B for 2019 and the distribution ratio. Own calculatios. **Table S3:** Quota allocation cod and herring for the different business types for the year 2022. The quota allocation is based on BLE (2022a) (Table S1), assuming that the quota allocated to the organized main business is divided between Types A and B the same way as in 2019 (based on Table S2). **Table S4:** Fish species landed in the German Western Baltic Sea. Landings of the most common fish species besides herring and cod for Mecklenburg-Western Pomerania (MV) and Schleswig-Holstein (SH) for 2021 from the Western Baltic Sea (IIIc 22 and IIId 24) based on LALLF (2021) and LLUR (2021). **Table S5:** Price overview for 24 fish species harvested by the German Baltic fisheries. Overview of prices from direct marketing and marketing via wholesale, producer organization (PO), which were landed most frequently in 2021 in terms of volume according to the landing statistics of the states of Schleswig-Holstein and Mecklenburg-Western Pomerania. (Average values based on own surveys). (LLUR 2021; BLE 2021b, 2021c, 2022b). **Table S6:** Variable costs per business. The table lists estimates of the main variables cost items and the value each business of a certain type paid (on average) for this item during a year. This amount is then related to the amount of fish caught per year to obtain the cost parameter. **Table S7:** Overview fixed costs per year, differentiated according to business type. The table lists the amounts per costs category and main sources. While we list personal as fixed costs, they may also be variable, as some employees are paid in terms of revenue shares. **Table S8:** Overview of how different potential stock developments translate into German catch possibilities in the Western Baltic Sea (WBS). Based on model runs and own calculations. **Table S9:** Overview of the structures in different natural resource sectors. The different resource user types could be represented by our Sceario Tool and the allocation of use rights explored.