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A Review of Economic Assessments of Drought Risk Reduction Approaches in Agriculture

1. Introduction

Due to increasing greenhouse gas emissions, the global temperature is expected to continue rising, causing different types of change in climate (EEA, 2021). Coping with the negative effects of climate change is one of humanity's greatest challenges. One example of such effects is the increase in extreme events such as heat waves, floods, and droughts (IPCC, 2018). Of these different natural disasters, drought is the most elusive (Sahani et al., 2019). The duration, intensity, and impact of a drought are often unclear due to its complex nature: the impacts can accumulate over time and are difficult to quantify (Wilhite, 2022). While there is no universal definition of drought, in this paper it is understood as a period with lower-than-average precipitation resulting in lower water availability. Four different types of drought can be identified: meteorological, agricultural, hydrological, and socio-economic drought, mentioned in order of increasing severity (Wilhite, 2022). All types stem from a precipitation shortage, but the vulnerability of the affected area determines whether a meteorological drought can become more severe (UNISDR, 2011). Population growth and unsustainable water management put an anthropological strain on water supply and demand (FAO, 2016). The combination of increased intensity and frequency of droughts, and unsustainable water management poses a great threat to water availability. This threat increases due to climate change which intensifies the natural pressure and is a driver of disaster risk (United Nations, 2015). To prevent new and minimize existing disaster risks, the Sendai Framework for disaster risk reduction was created (United Nations, 2015). This systematic approach allows for the identification, assessment, and reduction of disaster risk. Risk is determined by hazards, and by the vulnerability and exposure to these hazards (Cardona et al., 2012). Similarly, drought risk is determined by the likelihood of a drought event, the exposure to drought, and the vulnerability of the assets and people exposed (Vogt et al., 2018). While disaster risk management needs to integrate multiple hazards, drought risk reduction requires special attention. Drought risk is often underestimated since its impact is less visible compared to other natural hazards. Yet, severe droughts can cause immense economic damage, as well as threaten livelihood, food security and degrade ecosystems. Quantification of the full costs of drought is crucial in improving drought risk management (United Nations Office for Disaster Risk Reduction, 2021). Economic assessments are needed to support the development of drought risk management, providing clear information on the benefits of taking risk-reducing measures (Venton et al., 2019). Additionally, the results of the economic assessments aid in identifying high-risk areas and sectors, facilitating resource allocation decisions, and creating incentives since the economic advantages of drought risk reduction measures are highlighted. Especially the agricultural sector is highly vulnerable (Wilhite, 2022). Preparing for drought is crucial here since agriculture is the world's largest user of water as well as a major cause of water pollution (FAO, 2016).

The negative impacts of drought on the agricultural sector include lower crop yields and soil degradation (FAO, 2021). These can in turn lead to loss of income, unemployment, famine, migration, and loss of life (Gerber & Mirzabaev, 2017). Drought management is needed to minimize the negative effects resulting from this calamity. Historically, drought management is reactive, applying relief measures that are often untimely (Wilhite et al., 2014). However, these emergency responses often increase vulnerability to drought by increasing the reliance on government support of those affected. In recent years the call for an integrated drought

management approach has increased, to address the root causes of vulnerability (Bazza et al., 2015). Taking a proactive integrated drought management approach allows decision-makers to prepare for drought and minimize the expected damages (WMO & GWP, 2014). A successful drought policy should consider the three pillars of drought management: 1) Monitoring and early warning, 2) Impact and vulnerability assessment, and 3) Mitigation, preparedness, and response (IDMP, 2021). Implementing efficient drought risk reduction approaches proactively, will strengthen countries' resilience and reduce their vulnerability to drought.

While there is a multitude of literature concerning the development of drought risk management, there are still several barriers that cause nations not to apply a proactive approach (FAO, 2019). These could consist of no political will, limited investments, or a lack of knowledge (WMO & GWP, 2014). Proactive drought risk management can reduce future vulnerability to drought through drought risk reduction approaches, yet the implementation of these measures is lagging. This is often caused by a lack of knowledge about the costs and benefits since drought impacts are difficult to quantify. However, research shows that the costs of investing in proactive drought risk reduction measures are far lower than the damages suffered if these measures are not implemented (Venton et al., 2019). For every US$ spent on drought risk reduction, at least 2 US$ can be saved on future disaster costs (Logar & van den Bergh, 2013). The issue remains that private investments are necessary for drought risk reduction measures, while the benefits gained are partly external to the investor. For example, proactive drought risk management is assumed to generate benefits such as avoided damages during drought events, stimulation of economic activity due to this reduced risk, and the development of co-benefits of specific drought risk-reducing measures (Vogt et al., 2018). These benefits are known as the Triple Dividend of resilience (Tanner et al., 2015). In the agricultural sector, possible drought risk-reducing measures can focus on increasing water availability, increasing water use efficiency, increasing crop resilience to drought, or ensuring farmers' livelihood through insurance mechanisms (EIP-Agri, 2016). Investing in proactive drought risk-reducing measures can reduce farm vulnerability and cause co-benefits such as ecosystem services.

Various drought risk-reducing measures exist but their implementation is lagging (Vogt et al., 2018). Planning for drought risk reduction requires careful assessment of the economic, environmental, and social costs and benefits of the measures (UNFCCC, 2011). While drought risk management has improved in recent years, considering initiatives and frameworks such as the Sendai Framework (United Nations, 2015), European Drought Observatory for Resilience and Adaptation (EDORA, 2022), and the Integrated Drought Management Program (IDMP, 2021), the economic assessment of drought risk reduction approaches remains complex (Vogt et al., 2018). Specifically, information on the costs, benefits, and effectiveness of drought risk reduction measures is difficult to obtain, due to climate uncertainty for example. Several methods exist that allow the economic assessment of adaptation measures, such as Cost-Benefit Analysis (CBA), Cost-Effectiveness Analysis (CEA), or Multi-Criteria Analysis (MCA) (UNFCCC, 2011). Each method has its strengths and weaknesses as well as a specific context in which they are most appropriate to use. Note that it is not the aim of this paper to identify a single best method to economically assess drought risk reduction measures. Regardless of the specific method applied, certain elements can be included in each assessment to avoid flawed results (UNFCCC, 2011). Since the outcomes of economic assessments are typically used to aid the decision between alternatives, under- or overestimations of the outcomes can skew the decision between alternatives. For example, focusing on direct costs and benefits of drought risk reduction approaches, excluding co-benefits and other externalities, can lead to a preference for grey infrastructure rather than nature-based solutions (NBS). Grey infrastructure refers to

human-engineered infrastructure, attempting to control nature as opposed to using natural processes in the implemented measures. Additionally, lock-in mechanisms can obstruct investments in these NBS. However, NBS offer immense potential in addressing the negative effects of climate change-related disasters, while creating co-benefits, compared to grey infrastructure (Seddon et al., 2020). Incomplete assessments of drought risk reduction approaches could result in inaccurate conclusions concerning the planned investments. Investing in inefficient measures can result in a loss of financial resources while not effectively decreasing damages. To avoid this, it is crucial to determine which elements should be included in the economic assessment of drought risk reduction approaches and whether this is effectively carried out.

It is key for decision-makers to properly translate the theory of economic assessment into practice when deciding on climate adaptation measures. This also applies to measures specifically related to drought risk reduction. The costs and benefits of different measures need to be assessed carefully, considering the current and estimated future risk of droughts as well as the local vulnerability to drought impacts. The results of these assessments can then be used to identify the most effective drought risk reduction approaches. However, both literature and data on the economic assessment of drought risk reduction approaches are fragmented, which complicates this step of drought risk management. This could mean that the economic assessment of drought risk reduction approaches is often incomplete in practice, resulting in an underestimation of the different related benefits. Great progress has been made in: identifying which economic assessment methods are needed in the process of drought mitigation (Logar & van den Bergh, 2013), recognizing the economic impacts of drought (Ding et al., 2010), including vulnerability in drought risk management (King-Okumu et al., 2020) and providing guidelines for proactive drought risk management (Vogt et al., 2018). Additionally, frameworks have been developed to better include the effects of climate change in climate adaptation strategies (UNU-EHS, 2020). However, it is not always clear how these recommendations and guidelines translate into practice, particularly in the field of drought risk management.

This paper fills this caveat by 1) evaluating how several criteria for the economic assessments of climate adaptation measures are applied in practice, specifically for drought hazards in the agricultural sector, and 2) proposing a framework for the economic assessment of drought risk reduction approaches. A systematic literature review is applied where economic assessments of drought risk-reducing measures are bundled and evaluated based on a set of guiding criteria. The results indicate how the guidelines on economic assessments of climate change are translated into the practice of drought risk management, specifically in the agricultural sector. The proposed framework is intended to improve the economic assessments of drought risk reduction approaches. The framework indicates which criteria could be included to perform a comprehensive economic assessment. The specific method of economic assessment still needs to be determined, depending on the research purposes. These results can assist practitioners in their decision planning of drought risk management, and subsequently implementing the most fitting drought interventions.

2. Methods

The methods used in this review paper consist of two different elements. Firstly, a systematic literature search was conducted to identify different cases in which an economic assessment of drought risk reduction approaches was used, more specifically related to the agricultural sector. Then different criteria were identified that can be included during the assessment of climate change adaptation measures. The selected records were evaluated based on these criteria to study the translation of theoretical guidelines into practice.

2.1. Literature search

A systematic literature search was executed for this study. The flowchart of the literature search and record selection is depicted in Figure 1. The databases used were ISI Web of Science and Scopus. First, the search string "Agriculture" AND "Drought" AND ("Adaptation" OR "Mitigation") was applied to identify related records. This resulted in a preliminary list of 4,243 articles. After removing duplicates, the list consisted of 2,025 articles. This list was further filtered by formulating inclusion criteria to remove research that is not relevant to this study. Since the topic of this review is the economic assessment of drought risk reduction approaches, articles that do not mention synonyms of "approaches", such as "measures", "practices" and "strategies" in their abstract/title/keywords were excluded. This decreased the selection of articles to 1,099. This selection of records was further filtered by only including articles that refer to "Economic Assessment", "Cost-benefit~", "Cost-effective~", and "Multi-criteria~". Through these search queries, the total number of articles identified was reduced to 85. To remove nonrelevant research, the title and abstract were screened. If the emphasis of an article was not on drought intervention measures' economic assessment, the article was left out. For example, studies purely monitoring drought in a region were eliminated. This screening reduced the number of articles to 12. No specific time range for the literature search was applied. While this paper focuses on the evaluation of economic assessments on drought risk management in scientific publications, we acknowledge the abundance of economic assessments for (non-)governmental planning and evaluation. The latter so-called grey literature, which is not published in scientific journals, may alter the conclusions from this publication. It is assumed however that pragmatic or routinely operated economic assessments exclude some elements of economic assessments, and do not have full comprehensive economic assessments as part of their design. While the evaluation of the use of economic assessments in grey literature is out of scope for this publication, we did include the evaluation of two 'grey' reports in this paper for illustrative purposes. These reports were selected since they both apply the Economics of Climate Adaptation framework (ECA) and are gathered from well-known institutions, namely the International Institute for Sustainable Development and United Nations University. In total, 14 different studies will be analyzed in this review paper as shown in Table 1. The process of the systematic review is depicted in Figure 1.

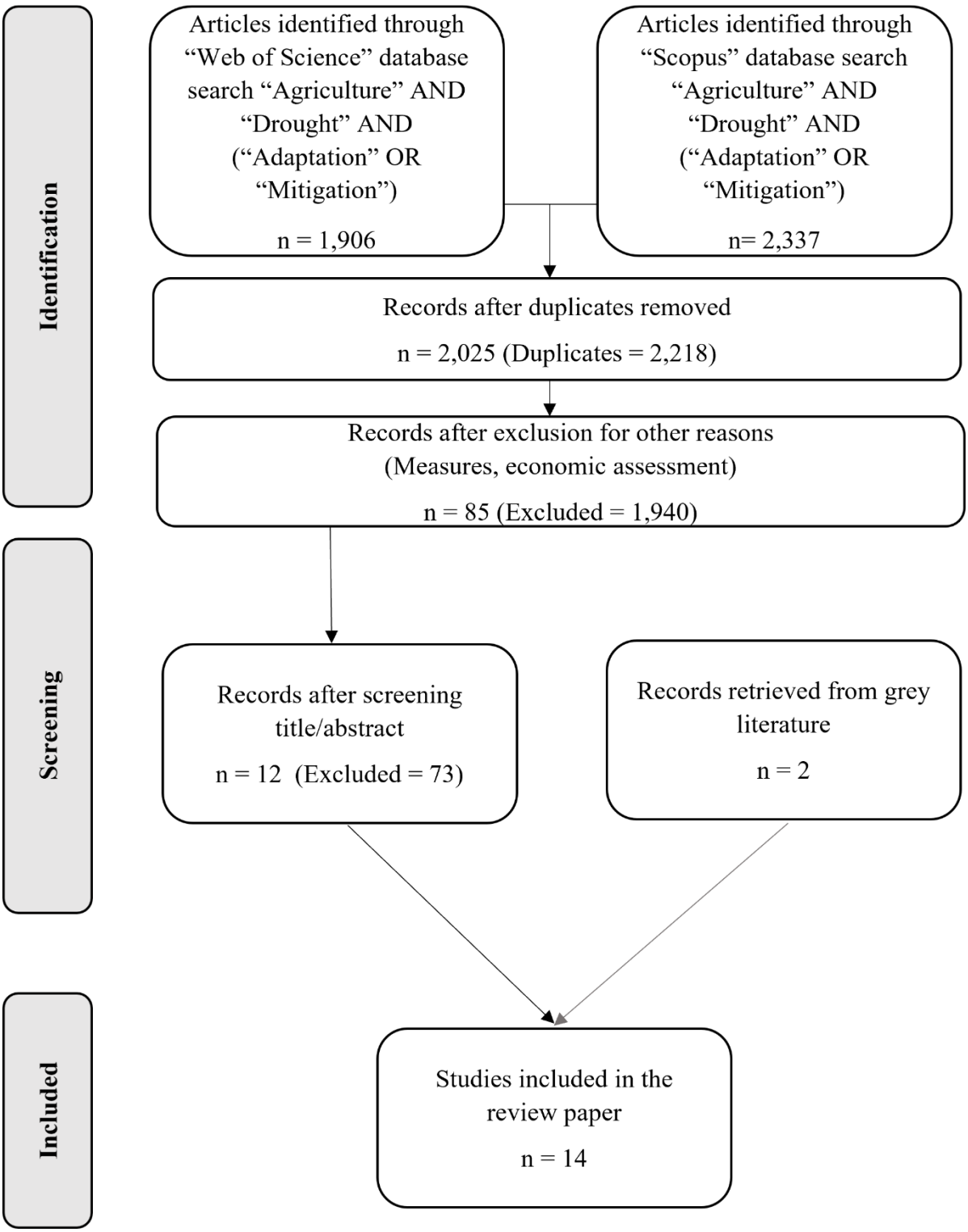

Figure 1 Flowchart of record search and selection. Adapted from Page et al. (2021)

Table 1 Included records

#	Title	Source	Journal
1	*Marginal Abatement Cost Curves for Water Scarcity Mitigation under Uncertainty*	(Sjöstrand et al., 2019)	Water Resources Management
2	*Cost–benefit analysis of climate change adaptation measures in Bosnia and Herzegovina*	(Cupac et al., 2020)	Euro-Mediterranean Journal for Environmental Integration
3	*Risk-Based Assessment of Drought Mitigation Options: The Case of Syros Island, Greece*	(Giannikopoulou et al., 2017)	Water Resources Management
4	*The Productive, Economic, and Social Efficiency of Vineyards Using Combined Drought-Tolerant Rootstocks and Efficient Low Water Volume Deficit Irrigation Techniques under Mediterranean Semiarid Conditions*	(Azorin & Garcia, 2020)	Sustainability
5	*Adaptation strategies for water supply management in a drought prone Mediterranean river basin: Application of outranking method*	(Kumar et al., 2016)	Science of the total environment
6	*How can irrigated agriculture adapt to climate change? Insights from the Guadiana Basin in Spain*	(Varela-Ortega et al., 2016)	Regional Environmental Change
7	*An Economic Assessment of Local Farm Multi-Purpose Surface Water Retention Systems under Future Climate Uncertainty*	(Berry et al., 2017)	Sustainability
8	*The implications of drought and water conservation on the reuse of municipal wastewater: Recognizing impacts and identifying mitigation possibilities*	(Tran et al., 2017)	Water Research
9	*Coping with drought: Lessons learned from robusta coffee growers in Vietnam*	(Byrareddy et al., 2021)	Climate Services
10	*Costs and benefits of climate-smart agriculture: The case of the Dry Corridor in Guatemala*	(Sain et al., 2017)	Agricultural systems
11	*Understanding the economics of climate adaptation in Trinidad and Tobago*	(Inter-American Development Bank, 2014)	/
12	*Ethiopia Drought Risk*	(Waldschmidt et al., 2021)	/
13	*Evaluating Water Infrastructure and Agriculture Practices for Drought Adaptations in East Africa: A Combined Hydrological and System Dynamics Approach*	(Agusdinata, 2016)	Proceedings of the Sixth IEEE Global Humanitarian Technology Conference
14	*A cost-benefit analysis of climate-smart agriculture options in Southern Africa: Balancing gender and technology*	(Mutenje et al., 2019)	Ecological Economics

The included articles were then carefully read and reviewed. After a broad identification of the different research goals and measures applied, a further comparison was made regarding their economic assessment methods. These were evaluated based on their aptitude for assessing the costs and benefits of drought risk reduction approaches. Important to note is that the selected records sometimes assessed several sectors or several climate hazards, not limited to agriculture and droughts. Due to the limited availability of papers specifically focused on the economic assessment of drought risk reduction approaches in agriculture, these records were still included. This should not be an issue in the evaluation since the criteria used in this paper apply to the assessment of the costs and benefits of climate adaptation measures in the broadest sense. Only the single hazard of drought will be considered during the evaluation of the methods used.

2.2. Assessment criteria

When planning for climate adaptation, it is important to assess and select the different possible measures (U.S. Climate Resilience Toolkit, 2022). Different measures can be selected and evaluated through various approaches, depending on context-specific objectives. Out of the recommendations made by the UNFCCC (2011), several criteria on which the different assessment methods can be evaluated were derived. While many methods exist, three of the most common are CBA, CEA, and MCA. In short, a CBA can be applied if the assessment has one objective, the impacts are measurable, and the benefits can be expressed in monetary terms. While it allows for comparison under a common metric, it cannot be applied with non-monetized impacts and requires subjective input for its discount rate. A CEA differs in this aspect in that the benefits can be expressed in non-monetary terms. However, CEA insufficiently addresses equity and uncertainty. Should the assessment have multiple objectives, measurable impacts and benefits not expressed in monetary terms, an MCA can be more fitting. An MCA can include monetary and non-monetary costs and can address several criteria such as equity. However, the assessment of measures is subjective and cannot easily be compared. These methods differ in their process, outcome, and applicability. Yet regardless of the assessment method chosen, several criteria can be included to improve the assessment. These different criteria are described in Table 2, and other sources were sought that underline their importance.

Table 2 Criteria for the economic assessment

Criteria	Brief description	Sources
Impact/Vulnerability analysis	Impact and vulnerability analyses aim to discover drought's past and potential future impacts and assess their roots. While it is crucial to assess the impacts of droughts now and in the future, a distinction needs to be made between groups' predisposition to be adversely affected.	(Bazza et al., 2015; IDMP, 2021; IUCN, 2020; King-Okumu et al., 2020; UNFCCC, 2011)
Stakeholder engagement	Involving stakeholders in the assessment process creates ownership, increases the chance of implementation, and is a valuable source of local information. Active participation leads to better acceptance and results. Excluding stakeholders could result in missed opportunities and a loss of information.	(IUCN, 2020; UNFCCC, 2011; WMO & GWP, 2014)
External effects	Adaptation options can lead to ancillary costs and benefits, which are often not considered in basic economic assessments. However, these co-benefits (or costs) can result in higher (lower) values attached to adaptation projects and should be considered to estimate the entire impact of the measures.	(Chambwera et al., 2014; Gerber & Mirzabaev, 2017; NWRM, 2013b; UNFCCC, 2011; Venton et al., 2019)
Multiple assessments	Multiple assessments of the different drought risk reduction approaches should be made to increase the robustness of the outcomes. This allows the decision-maker to consider all relevant objectives and local circumstances in the selection process.	(UNFCCC, 2011)
Equity	Equity refers to the desirability of the distributional effects among stakeholders. It is important to discern which groups will benefit and which will pay the price of the measure.	(NWRM, 2013a; UNFCCC, 2011; WMO & GWP, 2014)
Viability of short- and long-term measures in a broad context	When assessing measures, it is crucial to look at their sustainability and economic viability. The effects of short- and long-term measures need to be investigated in the broad development and policy context. This allows for the inclusion of intersectoral costs and benefits.	(UNFCCC, 2011)
Sensitivity analysis	Sensitivity analysis needs to be conducted to determine how the output changes if individual key variables (such as the discount rate) are changed.	(European Commission, 2015; UNFCCC, 2011)

These seven criteria provide an indication of which elements can be included when performing the economic assessment of climate adaptation measures. However, each assessment should still be carefully planned, depending on the local context. Different methods of economic assessment can include these criteria, and there is not one single best method. What these criteria offer is the possibility to evaluate the aptitude of carried-out economic assessments and discover which elements can be improved upon. In this review paper, the seven different criteria are applied to economic assessments specifically focused on drought risk reduction approaches. The methods used in the included records will be evaluated based on these criteria. This will allow the identification of criteria that are often excluded in practice. Note that the sole objective is to compare each assessment paper separately to the evaluation criteria, to discover in which aspects practitioners can improve. No comparison of the different assessments can be made due to differences in spatiality, objectives, measures considered, or local context. Differences in the geographical characteristics between the study site of the included records were also not

considered. Note that the described criteria can be used for evaluating the assessment of climate adaptation in different sectors, as well as different climate hazards. In this review paper, the selection is focused on the agricultural sector and the climate hazard of drought. Each of the selected records is scored on the seven criteria.

3. Results

Table 3 gives an overview of how the different assessments carried out in practice score on each of the criteria. This intuitive overview depicts how the studies in practice score per criterion. For each record, the country where the research was conducted is also included. While the records are few, the geographical spread is broad with six papers discussing cases in developing countries.

Table 3 Scoring on criteria

Records	Authors	Countries	Method of economic assessment	Impact - Vulnerability assessment	Stakeholder engagement	External effects	Multiple assessments	Equity	Viability in the broad context	Sensitivity analysis
1	Sjöstrand et al. (2019)	Sweden	MACC	0	+	0	-	-	0	++
2	Cupac et al. (2020)	Bosnia & Herzegovina	CBA	-	-	0	-	-	0	-
3	Giannikopoulou et al. (2017)	Greece	CEA	++	+	-	+	-	-	-
4	Azorin and Garcia (2020)	Spain	CBA	-	-	-	0	-	+	-
5	Kumar et al. (2016)	Spain	MCA Outranking	0	+	+	+	0	+	-
6	Varela-Ortega et al. (2016)	Spain	Economic Hydrological Modelling	+	+	0	0	-	0	-
7	Berry et al. (2017)	Canada	Dynamic Simulation Model	+	-	+	0	+	+	+
8	Tran et al. (2017)	United States	CEA	-	-	0	+	-	0	+
9	Byrareddy et al. (2021)	Vietnam	Comparative Assessment	0	0	-	+	-	-	-
10	Sain et al. (2017)	Guatemala	CBA	-	+	+	0	-	0	+
11	Inter-American Development Bank (2014)	Trinidad & Tobago	ECA, Damage Function	-	-	-	0	-	+	+
12	Waldschmidt et al. (2021)	Ethiopia	ECA, CBA	++	+	+	+	0	0	-
13	Agusdinata (2016)	Ethiopia, Kenya, Somalia	CEA	+	-	-	0	+	0	-
14	Mutenje et al. (2019)	Malawi, Mozambique, Zambia	CBA	0	+	-	+	-	-	-

CEA = Cost-Effectiveness Analysis, CBA = Cost-Benefit Analysis, MCA = Multi-Criteria Analysis, MACC= Marginal Abatement Cost Curve, ECA = Economics of Climate Adaptation. - = A negative score is given when the criterion is not included in the assessment. 0 = A neutral score is given when the criterion is included in the assessment but in a limited manner + = A positive score is given when the criterion is included sufficiently. ++ = An excellent score is given when the criterion is included extensively

The interpretation of the results above will be described in further detail in the discussion section. In Figure 2 the number of criteria that earned a positive or neutral score (++, + or 0) are shown per record. In Figure 3 the number of positive scores is depicted per criterion. This facilitates the interpretation of the translation of the theoretical criteria to practice.

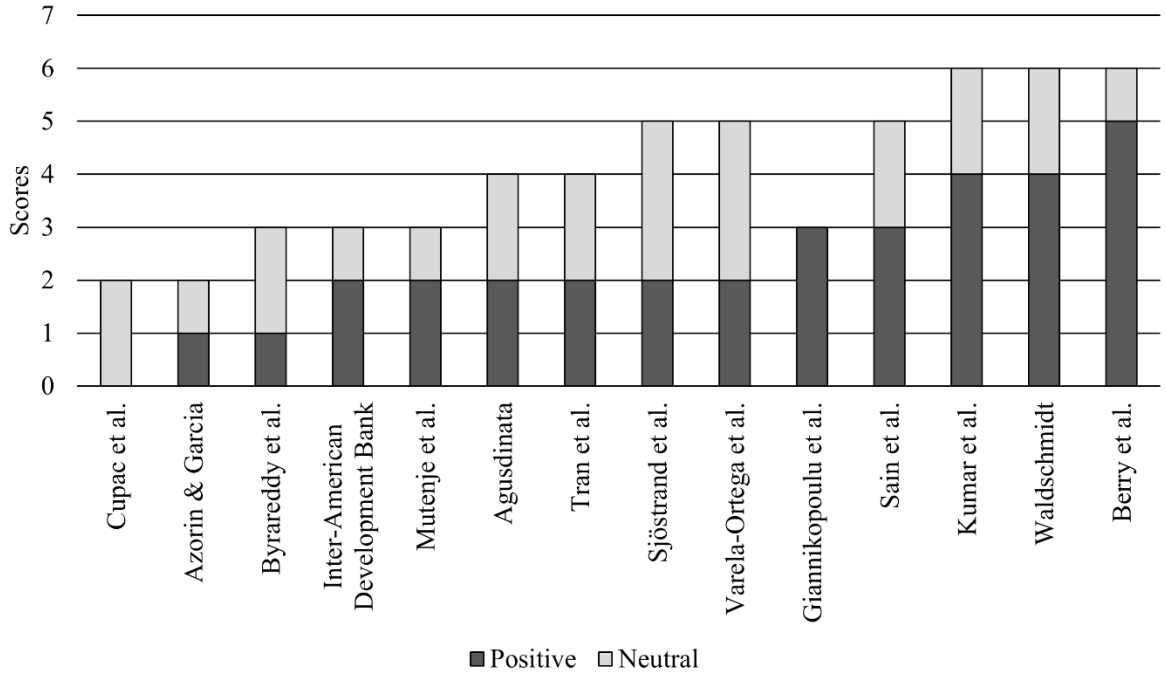

Figure 2 Positive and neutral scores per record

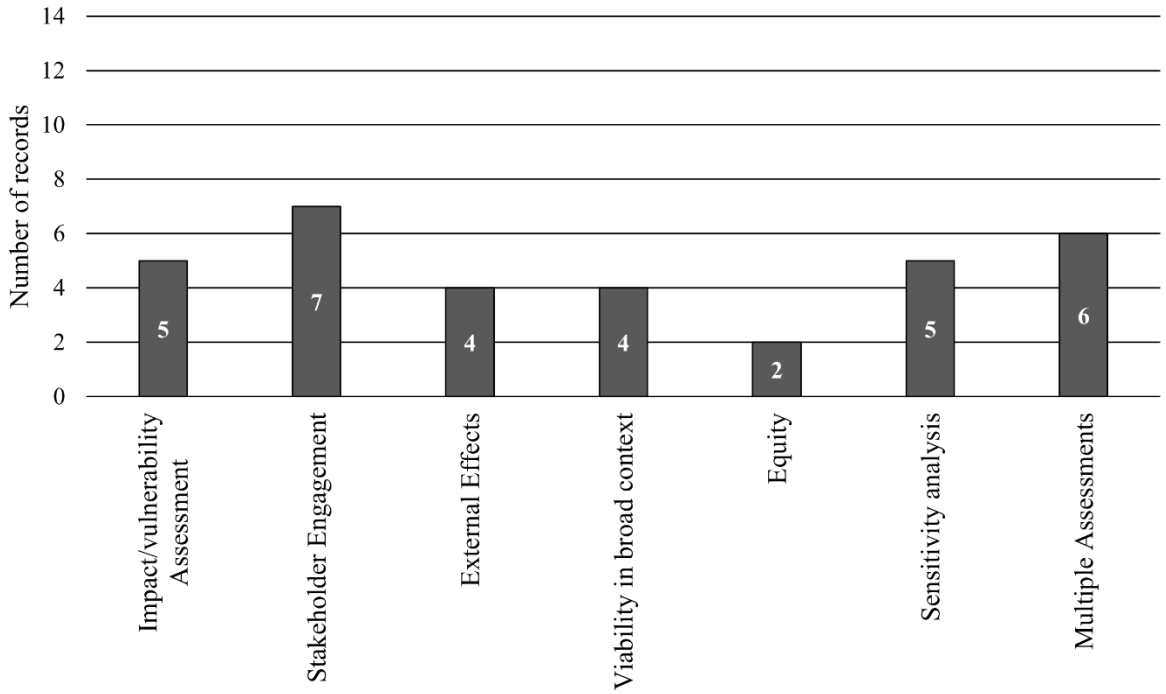

Figure 3 Positive scores per criterion

4. Discussion

This literature review evaluates the quality of economic assessments of drought risk reduction approaches in practice based on evaluation criteria. More specifically, the agricultural sector is investigated due to its inherent vulnerability to drought. In our systematic review, mostly academic literature is considered. A limited number of grey literature reports is included since these studies are closely related to practice and are intended to comprehensively assess drought risk-reducing measures to provide policy support. We only illustratively included two grey literature reports, but more reports of this type surely exist. It could be the case that academic articles score better on the seven criteria since they are assumed to be better substantiated compared to grey literature. Our results however show comparable results between the grey and academic literature. Due to the specificity of the investigated subject, only a small number of records could be included. While this could already give a first indication that the current topic poses a caveat in the literature, other authors might be able to distinguish a broader selection of records related to this topic. One could claim that the difference in results in Table 3 is due to the large differing topics and methods of the included records. Some academic articles focusing on a specific method might not aim to perform a comprehensive assessment of a drought risk reduction measure, and thus by default do not meet all criteria. However, the criteria are sufficiently broad to the extent that they can be interpreted over various climate hazards and assessment methods. The exclusion of some of the seven criteria can be justified but has to be acknowledged. The results of this review paper can aid decision-makers in their drought management planning process, and subsequently, local practitioners in the assessment of their investment decision regarding drought risk reduction approaches.

Seven different criteria are identified to remind the assessor of different elements to be considered to avoid underestimation of the actual costs and benefits of the project. Including these criteria in the economic assessments can provide more extensive outcomes, since the results show that the different criteria are never included simultaneously in the economic assessments. Depending on the purpose of the assessment in the planning stage, underestimations can be accepted. However, when the final investment decision needs to be made, improving the accuracy of the estimation is necessary. It is possible that aside from the seven identified criteria, other authors and practitioners can find additional aspects that could be included in the economic assessments, depending on their research goals. However, applying these seven criteria can already improve the outcomes. Furthermore, these criteria are broad and open to interpretation. The evaluation of the criteria as shown in Table 3 can be the subject of discussion since there is not a single correct way of fulfilling them. However, the given overview is meant to indicate which elements are often left out of the different assessments in practice. Figure 3 and Table 3 show that the criteria of equity, external effects, and viability in the broad development context are often not addressed sufficiently. The results vary greatly between the different records, and it does not seem that there exist typical combinations of criteria that are applied together. At most five out of the seven evaluated criteria are sufficiently addressed together in one economic assessment. In this section, the importance and possible implementation is discussed per criterion. Finally, a Framework for the Economic Assessment of Drought Risk Reducing Approaches is developed based on the different criteria, to aid practitioners in their research and inspire more extensive economic assessments.

4.1. Impact/vulnerability assessment

Impact and vulnerability assessment is a crucial aspect of climate adaptation planning, as well as of drought risk management (IDMP, 2021). Impact assessment is essential since it allows the identification of current and future expected damages of droughts. When assessing the benefits of drought risk reduction, avoided damages are often used to quantify the benefits of

implementation (United Nations Office for Disaster Risk Reduction, 2021). Vulnerability is more difficult to quantify due to its multidimensional nature. It remains important to assess the vulnerability between and within groups since more vulnerable systems are impacted disproportionately by the effects of climate hazards (IPCC, 2022). Economic assessments often fail to take into account these vulnerability aspects, focusing solely on the monetary impact and underestimating the environmental or social effects (King-Okumu et al., 2020). The inclusion of proactive vulnerability assessments can help in designing the appropriate drought risk reduction approaches (UNCCD, 2019).

While the aforementioned literature emphasizes the importance of including impact and vulnerability analysis in the economic assessment of drought measures, the results show that the implementation is still lagging. Only four of the included records were awarded a positive score regarding their impact and vulnerability analysis. The reports of Giannikopoulou et al. (2017) and Waldschmidt et al. (2021) both received an excellent score, while they used entirely different approaches. This indicates that there is not one correct way of performing the analysis, and multiple methods are applicable. What remains important in all cases, is that the impact of drought in terms of losses/damages is identified, now and in the future. A distinction between the different types of impact (land-based, water-related, and people-centered) further improves the analysis. As for the vulnerability analysis to drought, two types of assessment can be identified. The first one relates to reducing vulnerability, which can be identified by comparing the impacts of a baseline scenario to the impacts of other scenarios with measures taken. While useful, this is deemed insufficient in this review paper. A second type of vulnerability assessment needs to be included, where the root causes of vulnerability are assessed. This allows for the identification of the most vulnerable subjects and the drivers of vulnerability that need to be addressed (Bazza et al., 2015). Most of the records that did not receive a positive score, did not adequately perform a vulnerability assessment. The vulnerability analysis is often not carried out due to a lack of data. When that is the case, estimates can be made based on expert opinions or practitioner surveys. It is better to include rough vulnerability assessments, acknowledging their limitations, as done by Agusdinata (2016) and Waldschmidt et al. (2021) than not addressing vulnerability at all. Impact and vulnerability assessments should always consider the local context. While no universally applicable methods can be recommended, these elements need to be incorporated to avoid the exclusion of important results (UNCCD, 2019).

4.2. Stakeholder engagement

Engaging stakeholders during the economic assessment of drought risk reduction measures is crucial since these measures are extremely context-dependent (UNFCCC, 2011). Stakeholders' experience and expertise are important sources of information as they aid in the identification of local challenges and allow validation of initial results. Aside from being an important source of information, their involvement can also increase ownership and facilitate the implementation of the selected measures. Most of the records engage stakeholders in the economic assessment of the different measures. Stakeholder engagement is also identified as an important step in drought risk management policy (United Nations Office for Disaster Risk Reduction, 2021). A participatory approach where stakeholders can provide their input and share their preferences will improve the outcome and implementation greatly. Several authors include stakeholders in the different steps of their research, engaging in a process of co-creation, such as Sain et al. (2017), Sjöstrand et al. (2019), Varela-Ortega et al. (2016) and Waldschmidt et al. (2021). It is also important to include different types of stakeholders such as farmers, local citizens, and policymakers, and make sure that the stakeholder decisions are transparent and equitable regarding the gender, age, or background of the stakeholders (IUCN, 2020).

4.3. External effects

When assessing the impact of drought risk reduction approaches in agriculture, it is crucial to include external effects. External effects occur when an unrelated third party is positively or negatively affected by economic activities, yet these effects are not included in the price of consumption or production. While drought risk reduction approaches increase resilience to drought, they can also have socio-economic co-benefits which occur even without the presence of drought (Tanner et al., 2015). These can be seen as "no-regret" options. Aside from these co-benefits, external effects can also include co-costs (Chambwera et al., 2014). Not including externalities in the assessment of the measures can lead to incomplete results, disregarding their impact on third parties and ecosystems (Venton et al., 2019). While difficult to quantify, they can be assessed through quantitative, qualitative, or mixed methods, for example by looking at the cost of remediating damages in the case of negative external effects. Some of the reviewed papers attempted to quantify externalities. Kumar et al. (2016) assessed externalities in a broad sense through the use of indices related to environmental stress. Waldschmidt et al. (2021) included the assessment of ecosystem services when establishing the current vulnerability of their case study, as well as in stakeholder workshops regarding the selection of measures. Berry et al. (2017) and Sain et al. (2017) went one step further and were able to assign a monetary value to the resulting co-benefits of their selected measures. The lack of data and difficult valuation of externalities often impede the inclusion of external effects in the assessment of drought risk reduction approaches. However, recognition of their existence is needed, even if only a broad estimate of the economic value can be given. While these values are less certain than those calculated through the use of market data, it aids in the inclusion of the value of ecosystems present (Chambwera et al., 2014).

4.4. Multiple assessments

The decision on the implementation of drought risk reduction approaches can be affected by several factors, one of which is the output of the economic assessment. However, various economic indicators exist, and their results can differ greatly. Relying on a single indicator can lead to inaccurate conclusions, and a lot of information is lost. A single method of assessment is highly unlikely to take into account all relevant local circumstances and objectives (UNFCCC, 2011). An example of a study relying on a single assessment is that of Cupac et al. (2020), where the profitability index is calculated for different measures as the sole indicator. Using different methods of assessment, the robustness of the results can be increased substantially. For example, Mutenje et al. (2019) performed both a cost-benefit analysis and a mixed-method approach to evaluate the likelihood of farmers investing in different adaptation measures. Through this, not only indicators such as Net Present Value and Internal Rate of Return were calculated, but household characteristics that influenced the likelihood of implementation were also identified. Conducting multiple assessments allows the decision maker to consider the relevant local influential factors as much as possible, providing a broader evidence base for the benefits of implementing the selected measures. Of course, it is unrealistic to continuously assess a measure in different manners due to cost- and time constraints. However, relying solely on one a single method can lead to an underestimation of the related costs and benefits.

4.5. Equity

Distributional effects are often not considered when assessing drought risk reduction approaches, as shown in Table 3. Yet, taking into account which groups will be able to enjoy the benefits and which groups will have to bear the costs of the assessed measures is extremely important to the adaptation planner (UNFCCC, 2011). Economic assessments could address the equitability of the cost and benefit distribution of different measures (Chambwera et al., 2014).

Unfortunately, this appears challenging since few of the included records attempt to do so. A good example of taking into account the distributional effects comes from Agusdinata (2016) who estimates per assessed measure what the positive and possible negative effect is for different types of farmers in monetary terms. A very interesting example is found in the work of Berry et al. (2017), where it was distinguished who could benefit from the assessed measure, and a suggestion was made of which parties should invest to avoid farmers would have to bear the entire investment. It is possible to assess the distributional effects albeit in general terms. Both financial and social equitability needs to be pursued to improve the implementation of drought risk reduction approaches.

4.6. Viability of short- and long-term measures in the broad context

The results of the economic assessment of drought risk reduction approaches are ideally attained through interaction with stakeholders of different sectors and in consideration of the societal impact of these measures on both current and future generations. This way, the impact of these measures can be identified, not limited to one specific sector or timeframe, thus providing the local decision-maker with crucial information on the viability of their investment. These can address the capability of climate proofing, maintenance requirements, or income generation for example. However, it is important to not only look at the local current conditions but also at the broad development and planning context (UNFCCC, 2011). E.g., measures that might not be beneficial for a single farmer, could improve food security in the long term. Often the assessment and implementation of measures are still too focused on small-scale, sector-specific, short-term risks (IPCC, 2022). Considering the broad development and planning context allows for the sustainable upscaling and replication of drought risk reduction approaches (IUCN, 2020). There is no clear-cut definition of how to include this aspect. Possible options are the involvement of policy planners in the assessment, building scenario analyses to assess measures' viability in different development contexts (Kumar et al., 2016), taking into account the impact of the measure beyond the own sector (Berry et al., 2017) or making recommendations on how policies should change to increase the viability of the assessed measures (Azorin & Garcia, 2020). While various records consider the broad context to some extent, this is often still limited either in timescale or in scope. The inclusion of this criterion proves to be challenging but can aid in the viability assessment of drought risk reduction approaches and in turn facilitate their replication and upscaling.

4.7. Sensitivity Analysis

The last criterion relates to evaluating how the results can differ in the face of changing input variables. It is crucial to investigate how robust the outcomes are through the use of sensitivity analysis (UNFCCC, 2011). While uncertainty analysis can also provide useful results, the use of sensitivity analysis shows the applicability of the initial results. In most of the reviewed records, no type of uncertainty or sensitivity analysis is conducted. The studies of Tran et al. (2017) and the Inter-American Development Bank (2014) did perform a sensitivity analysis, on the interest and discount rates used respectively. Another study showed how the results changed due to changes in radiative forcing scenarios (Berry et al., 2017). The paper by Sjöstrand et al. (2019) applied different discount rates and carried out Monte Carlo simulations on the calculation of unit costs to attain probability distributions of the output variables. The results show that the inclusion of sensitivity analyses is rather limited in practice. Applying this can increase the robustness of the results and remove uncertainty regarding the benefits of implementation.

4.8. Summary of criteria scores

The results in Figure 3 and Table 3 show that the seven selected criteria are rarely translated effectively into practice. There is no clear pattern noticeable in the comprehensive application of the different criteria. Furthermore, none of the articles addressed all seven criteria simultaneously. The article by Berry et al. (2017) included the most criteria (5/7) of the selected records. The criterion "stakeholder engagement" was addressed most often, with 7 out of the 14 records attaining a positive score. Still, only half of the included records addressed this criterion. Including the different criteria in the economic assessment of drought risk reduction approaches broadens the scope and allows for the identification of all related costs and benefits. This can improve the results of the economic assessment and aid the decision-maker in the selection of drought risk reduction approaches.

5. Framework set-up

This review paper identified how general criteria for economic assessments of climate change adaptation are translated into practice, specifically for measures increasing resilience to drought with an emphasis on the agricultural sector. Information regarding proactive drought risk management is increasingly available (IDMP, 2021). This includes frameworks on how to support national policies on this subject (WMO & GWP, 2014). Frameworks or guidelines on how to reliably conduct economic assessments of climate adaptation, let alone drought risk reduction approaches, are considerably more difficult to find. Frameworks that address this issue do exist, such as the Economics of Climate Adaptation framework (UNU-EHS, 2020) or the triple dividend of resilience framework (Tanner et al., 2015). The ECA framework is more widely used for national policies to carry out a comprehensive assessment of climate risks (UNU-EHS, 2020). It consists of eight steps, comprising hazard modeling, valuation of assets, creating damage functions, and simulating adaptation measures' impacts. Yet, following this framework does not automatically result in reliable outcomes. This is illustrated by the difference in the scores of Waldschmidt et al. (2021) and the Inter-American Development Bank (2014) on the seven criteria, both following the ECA framework.

The criteria used in the current review paper are intended to distinguish key factors that increase the robustness and reliability of the results when included. There is no single best way of addressing the different criteria, therefore researchers are not bound to a specific method to include them. The different criteria are often interlinked yet challenging to apply due to, for example, a lack of reliable data available. However, it is better to address these criteria by working with estimations and benefit transfer values, acknowledging their limitations, than not attempting to include the seven factors. Based on the different criteria, a framework is proposed to aid practitioners in the economic assessment of drought risk reduction approaches. This framework provides criteria whose inclusion can improve the economic assessment of drought risk reduction measures, regardless of which assessment method is applied. The framework can be applied to evaluate outcomes of broader existing frameworks of climate adaptation. In Figure 4, a graphical representation of this framework is given. Increasing the implementation of these criteria in practice could avoid skewed results when assessing the costs and benefits of climate change adaptation measures. Specifically, in the field of drought risk management, the economic assessments can be improved greatly since the results show that several criteria are rarely applied. Finally, the Framework for Economic Assessments of Drought Risk Reducing Approaches (FEADRRA) depicted in Figure 4 will be explained briefly. The different criteria are highlighted concisely in the following paragraphs, to illustrate their importance as elements of FEADRRA. More information per criterion is given in section 4.

5.1. Impact and Vulnerability Analysis

The implementation of an impact and vulnerability analysis is crucial. A “no-measures” baseline scenario needs to be set up to assess the impact of (expected) drought. This impact should be expressed in factors of land (changes in crops/ecosystem services), people (effect on income, livelihood), and water (availability), estimated under different climate scenarios. Additionally, the affected groups’ vulnerability and the drivers of vulnerability in the study site need to be assessed as well. Then different scenarios where the measures are implemented need to be estimated, allowing for the identification of avoided damages or gains in land-, people- and water-related factors as well as the reduction in vulnerability of the affected groups.

5.2. External Effects

Identifying external effects, which can affect society as a whole, is important to set up policy measures that allow for the internalization of these external costs and benefits. Their inclusion can greatly affect the results.

5.3. Viability in the broad context

The viability of the measures should be regarded in the broad context of planning and development. The assessment should not be limited to the specific context but consider intersectoral effects and policy developments in the short- and long-term.

5.4. Equity

An equitable distribution of the costs and benefits needs to be made to improve the probability of implementation.

5.5. Multiple Assessments

Applying different indicators and, if the budget and timeframe allow it, applying different methods of economic assessment increases the robustness of the investment decision.

5.6. Sensitivity Analysis

Performing sensitivity analysis to address various types of uncertainty present in climate change adaptation and disaster risk management, improves the reliability of economic assessments.

5.7. Stakeholder Engagement

Engaging stakeholders during the economic assessment provides the decision-maker with important local information and improves the implementation of the different measures.

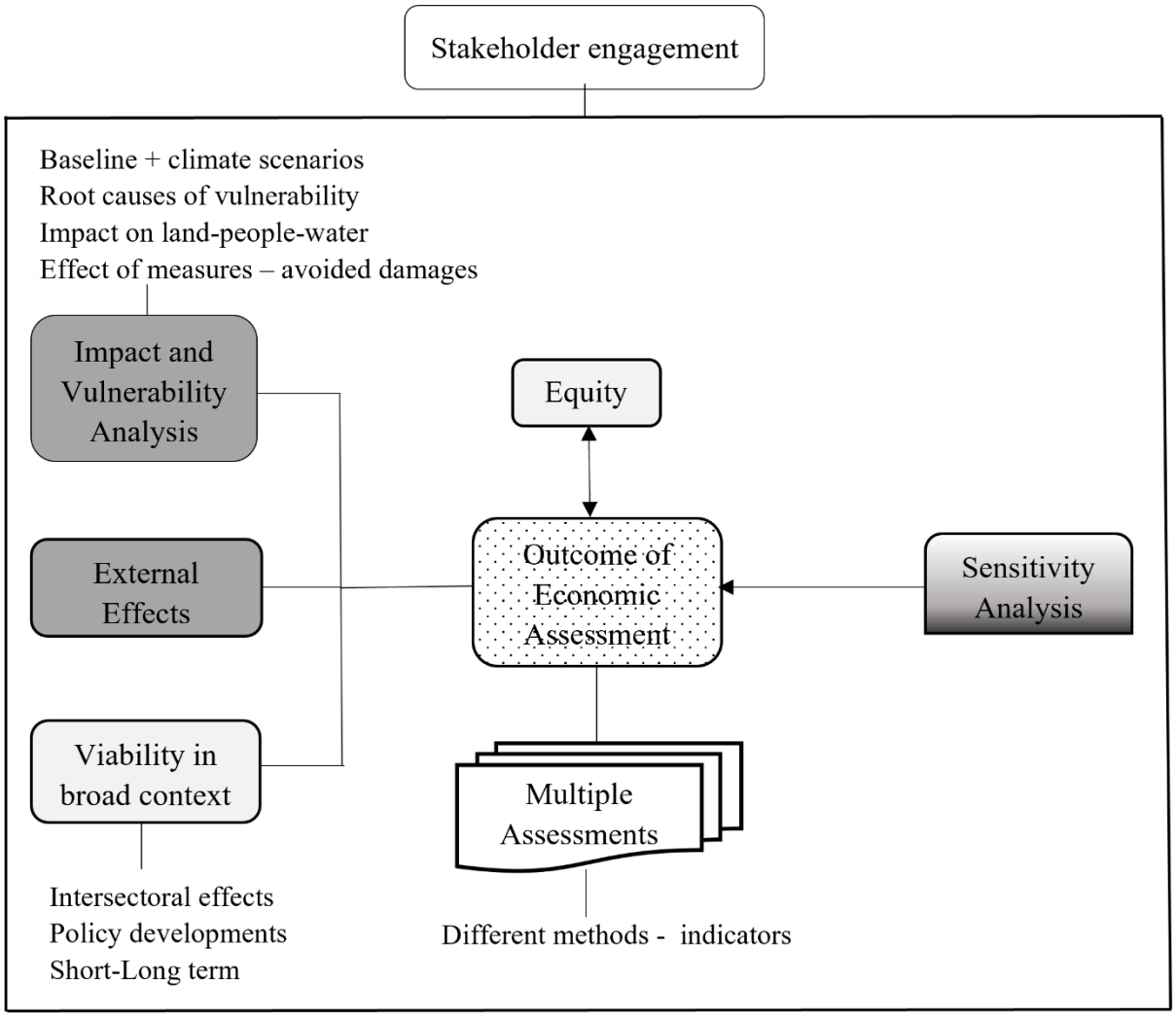

Figure 4 Framework for Economic Assessments of Drought Risk Reduction Approaches – FEADRRA

The different described criteria are categorized further by color code. Three different categories are made: “Outcome augmentation”, “Implementation”, and “Verification”. The first category relates to those criteria that, when addressed properly, improve the estimation of the costs and benefits related to drought risk-reducing measures. These criteria are colored dark grey. Those criteria that aid the implementation and distribution of the different measures are colored light grey. Identifying whether the distribution of the related costs and benefits is equitable for example, can facilitate further implementation. Criteria that improve the verifiability of the attained results are colored with a grey gradient. Lastly, those criteria that span all three categories are depicted in white. This categorization allows the researcher to better assess which criteria they need to include, depending on their aim and research goals. Of course, the criteria in the different categories can be combined. It does remain important to justify which criteria were not included in the analysis. When faced with such constraints, it is also possible to work with broad estimates of the different criteria. Acknowledging the flaws of the economic assessment promotes transparency, which is much needed in the field of drought risk reduction. The framework depicted in Figure 4 is intended as a stepping stone to improved economic assessments of drought risk-reducing measures.

In an ideal world, the framework depicted in Figure 4 can be executed completely and comprehensively. However, researchers are often faced with limited means, such as time- and budget constraints. Since not all criteria can likely be applied, they are ranked in Figure 5. The figure shows that researchers with limited means could first focus on the impact and

vulnerability analysis. This will provide them with a preliminary assessment. When more means are available to researchers, they could include the other criteria as well. Executing a full assessment, thus addressing every criterion, will be very time-, budget- and effort intensive. The proposed ranking allows researchers to attain the best results possible compared to their available means. Of course, other rankings of these criteria can be made since the research objectives are context dependent. Naturally, this depends on the aims and purposes of the specific research project. How the different criteria can and will be included, needs to be determined during the planning stage of the economic assessment.

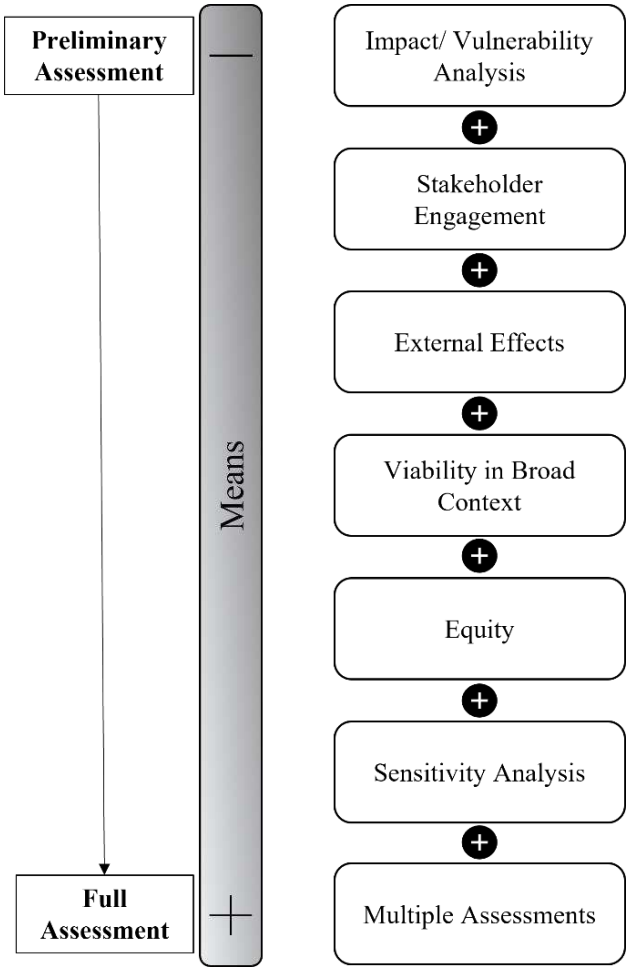

Figure 5 Implementation order of criteria

6. Conclusion

Decision makers are increasingly investing time and resources to engage in proactive drought risk management. One aspect of drought risk management is the selection of drought risk reduction approaches, to reduce vulnerability to drought. While the knowledge on this research topic is vastly increasing, little information is available on the economic assessment of such measures. Various frameworks and guidelines exist, but it is not clear how these can be translated into practice.

This literature review assessed how evaluation criteria for a reliable economic assessment of climate adaptation measures are addressed in practice for a single hazard. Specifically, drought risk reduction approaches with an emphasis on the agricultural sector are investigated. The systematic literature search resulted in a total of 14 relevant records that performed a type of economic assessment of drought risk reduction approaches. As shown in Table 3, the studies

have a high geographical spread, implying that the terminology used is not specific to a certain region. The 14 assessments were evaluated on seven criteria, derived from recommendations for assessing the costs and benefits of climate adaptation. Due to the generality of the criteria, they can be applied to a range of assessment methods for options in different sectors and climate hazards.

The results show that most of the included studies did not sufficiently address all seven criteria. While this does not indicate that the results of the respective studies are not useful, it could indicate that their results are skewed, since not all important factors are considered. The highest scoring criterion was "stakeholder engagement", with 7 out of the 14 studies receiving a positive mark for engaging stakeholders in their assessment methods. The three criteria with the lowest scores were: including equity (2/14), assessing viability in the broad development context (4/14), and including external effects (4/14). We can conclude that the different criteria concerning the economic assessment of climate adaptation measures are not properly translated into practice for drought risk management. This could be due to the high uncertainty of the data and estimates required to include these criteria. Another explanation could be the increasing complexity and time requirement of the assessments when more of the criteria are considered. Other causes such as a narrow focus on a specific outcome or pursuing general results that are applicable everywhere could also lead to a less comprehensive economic assessment. By not addressing the different criteria the results obtained might be skewed, causing an underestimation of the total costs and benefits of the different measures. By applying the seven recommendations to the assessments in practice, more reliable and robust results can be obtained. While the economic performance of adaptation measures is not the only factor to consider during the selection process, an increase in the reliability of the economic information can facilitate decision-making. Based on these criteria, a Framework for Economic Assessments of Drought Risk Reducing Approaches (FEADRRA) is set up. FEADRRA can be used to guide decision-makers in performing economic assessments more carefully. Their insights should also be shared with local practitioners, to improve their decisions regarding on-farm investments.

7. Limitations

Several limitations are present in this review paper. First, very few studies that fit the field of interest were found. This provides a first indication that there is sparse information available on this specific topic. Some records were included that also investigated different climate hazards or various sectors. Due to the generality of the used criteria, this should not lead to different conclusions. Secondly, the databases used primarily include English-language publications. Potentially relevant studies in other languages were not included due to this language bias. Thirdly, the criteria we used are mainly based on a single report of the UNFCCC and were applied to a single hazard assessment. Further research could also investigate their applicability to a multi-hazard assessment. Fourthly, most reports investigated here were academic. Two grey literature reports were added illustratively, and their results are similar to the academic articles included. It would be interesting to further assess how reports from grey literature score on the different criteria in future research since these reports might have applied more simple methods of assessment than academic literature. More research is required on why economic assessments appear so difficult in practice. Based on this, guidelines can be developed on practically applying economic assessments in climate adaptation, or more specifically on drought risk reduction. The creation of the FEADRRA is a first step in facilitating the process of economic assessments regarding drought risk-reducing measures and can aid practitioners in their assessments. However, the framework has not yet been evaluated in practice. The author intends to translate the FEADRRA into practice in future research.

AUTHOR'S STATEMENTS

Credit author statement

S. Vermeulen, J. Cools, and S. Van Passel designed the study. S. Vermeulen conducted the analysis and wrote the first draft. All authors contributed to writing and revising the manuscript.

Declaration of competing interest

The authors declare that they have no competing interests or personal relationships that could have influenced the work reported in this manuscript.

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