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

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ABSTRACT

Due to climate change, the frequency and intensity of droughts are expected to increase. To improve resilience to droughts, proactive drought management is essential. Economic assessments are typically included to decide on the drought risk-reducing investments to make. The choice of both methods and scope of economic assessments influences the outcome, and thus the investment choice. This paper reviews 14 actual economic assessments, evaluating the methods used based on seven criteria for economic assessments as derived from the United Nations Framework Convention on Climate Change (UNFCCC). The results show that in practice, economic assessments rarely address all criteria. Applying a limited number of criteria reduces the scope and narrows the approach, possibly leading to the underestimation of drought risk reduction approaches' related benefits. Applying the seven criteria in practice will improve the results of economic assessments of drought risk reduction measures, allowing for optimal investment selection. Based on the different criteria, a Framework for Economic Assessments of Drought Risk-Reducing Applications (FEADRRA) is set up to aid decision-makers.

KEYWORDS

Drought, Climate Change Adaptation, Disaster Risk Management, Agriculture, Economic Assessment, Literature Review

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INTRODUCTION

Due to increasing greenhouse gas emissions, the global temperature is expected to continue rising, causing different types of change in climate [1]. Coping with the negative effects of climate change is one of humanity's greatest challenges. Some of the expected effects are an increase in sea level, average temperature and precipitation variability. Extreme events such as heat waves, floods and droughts will also occur more often [2-5]. Of the different natural disasters expected to increase in both frequency and intensity due to climate change, drought is the most elusive [6, 7]. The duration, intensity and impact of a drought are often unclear. This is due to its complex nature: there is no universal definition of the phenomenon, the impacts are creeping, can accumulate and are difficult to quantify [8, 9]. In this paper, drought is understood as a period with lower-than-average precipitation resulting in lower water availability. It is important to discern drought from aridity. The latter can be understood as a permanent low water availability due to a low average annual precipitation [10]. Arid regions are already more vulnerable to water scarcity due to the low supply, but droughts can affect all regions of the world, both with high and low average rainfall [8, 11]. While droughts pose a natural threat to the water supply, human practices also threaten water availability. Population growth, the overexploitation of aquifers, and unsustainable water management put an anthropological strain on water supply and demand [8, 10, 12]. The combination of increased intensity and frequency of droughts, and unsustainable water management poses a great threat to water availability. This threat is increased due to climate change since this intensifies the natural pressure. Climate change is a driver of disaster risk [13].

To prevent new and minimise existing disaster risks, the Sendai Framework for disaster risk reduction was created [13]. 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 [14]. The risk to be subject to damages and economic losses is affected by the combination of the probability of occurrence and severity of a disaster event, the exposed assets and people and their intrinsic vulnerability and capability to manage the disaster [15]. Various organisations and frameworks exist to improve the process of disaster risk reduction, such as the Sendai Framework, Climate Risk-based Decision Analysis (CRIDA), and the United Nations Office for Disaster Risk Reduction (UNDRR) [13, 16, 17]. While disaster risk management needs to integrate multiple hazards, special attention needs to be paid to drought risk reduction. Drought risk is often underestimated since its impact is less visible compared to other natural hazards [15]. Yet, droughts can lead to severe social, economic and environmental damages. Four different types of drought can be identified: meteorological, agricultural, hydrological and socio-economic drought [8]. They are mentioned here in order of increasing severity. All types are caused by a lack of precipitation, but the inherent vulnerability and the water management practices of the affected area determine whether a meteorological drought can evolve into one of the more severe types [9]. Severe droughts can cause immense economic damage, as well as threaten livelihood, food security and degrade ecosystems [15]. While various sectors can be affected by droughts, especially the agricultural sector is highly vulnerable [8]. Preparing for drought is crucial here since this is the world's largest user of water as well as a major cause of water pollution [12].

The negative impacts of drought on the agricultural sector include lower crop yields and soil degradation to name a few [18]. These can in turn lead to loss of income, unemployment, famine, migration and loss of life in extreme cases [19]. Drought management is needed to minimise the negative effects resulting from this calamity. Historically, drought management takes a reactive approach, through relief measures that are often untimely [20]. However, these

emergency responses often increase vulnerability to drought by increasing the reliance on government support by those affected. In recent years the call for an integrated drought management approach has increased. Through this, the root causes of vulnerability can be addressed [21]. Taking a proactive integrated drought management approach allows decision-makers to prepare for drought and minimize the expected damages [22, 23]. A successful drought policy should take into account the three pillars of drought management: 1) Monitoring and early warning, 2) Impact and vulnerability assessment and 3) Mitigation, preparedness and response. 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 [11, 19, 22]. These could consist of no political will, no stakeholder agreement, limited investments or a lack of knowledge [17, 22]. Proactive drought risk management can reduce future vulnerability to drought through drought risk reduction approaches, yet the implementation of these measures is lagging. Countries that do not invest in proactive measures often do so due to a lack of knowledge about the costs and benefits. This lack of knowledge stems from the difficult quantification of drought impacts. However, several studies show that the costs of improving the resilience of affected areas to drought by investing in preparedness and drought risk reduction measures are far lower compared to the costs of damages suffered when reactive measures are taken [19, 24]. For every US$ spent on drought risk reduction, at least 2 US$ can be saved on future disaster costs [25]. The issue remains that private investments are necessary for drought risk reduction measures, while the benefits gained are also external. 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 [15]. These benefits are known as the Triple Dividend of resilience [26]. 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 (for example through insurance mechanisms) to name a few [27, 28]. Specific possible measures are increasing water storage capacity, conservation agriculture, planting drought-resistant crops, wastewater reuse for irrigation and drip irrigation. Investing in efficient drought risk-reducing measures can reduce the vulnerability of the farmer as well as cause co-benefits such as ecosystem services.

Various drought risk-reducing measures exist but their implementation is lagging [15]. Uncertainty exists regarding the effectiveness of different measures in drought risk reduction. There is no single best measure since their effectiveness is context-specific [29]. Selection of which measures to invest in should be carried out carefully, to avoid allocating resources that do not provide the sought benefits. Planning for drought risk reduction requires planners and practitioners to assess the economic, environmental and social costs and benefits of the approaches [28]. 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. While drought risk management has improved in recent years, considering initiatives and frameworks such as the Sendai Framework, European Drought Observatory for Resilience and Adaptation (EDORA) and the Integrated Drought Management (IDMP), the economic assessment of drought risk reduction approaches remains complex [13, 15, 23, 30-32]. While decision-makers are increasing the implementation of

drought risk reduction approaches, information on the costs and benefits of these investments is challenging to obtain.

The economic assessment of measures is an important step in disaster risk reduction. In the case of drought risk reduction, this is complicated by various factors such as the lack of reliable data due to uncertainty of the drought impacts. Furthermore, since climate change affects the intensity and severity of droughts, uncertainty in climate change predictions can also influence the estimations of drought impacts and possible costs and benefits of measures applied to reduce vulnerability to droughts. 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) [28]. For each of the methods above different sub-methods can be applied, in particular, to assess benefits. Each method has its strengths, weaknesses and controversies as well as a specific context in which they are most appropriate to use. Regardless of the specific type applied, certain elements should be taken into account in each assessment to avoid obtaining flawed results [28]. The outcomes of an economic assessment are typically used to compare various alternatives and consequently decide on the most fitting measure. However, under- or overestimations can skew the decision between alternatives. Focusing on direct costs and benefits of drought risk reduction approaches, and thus excluding the co-benefits and other externalities, e.g., can lead to a preference for grey measures rather than nature-based solutions (NBS). In addition, 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 [33]. 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. 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. It is the objective of this paper to compare the economic assessment methods of drought risk reduction approaches and evaluate them based on a set of guiding criteria. Through a scoping review, economic assessments of different measures will be bundled and compared. This will allow the identification of which elements need to be considered during the economic assessment of drought risk reduction approaches and to compare how this is translated into practice. These elements will be integrated into a framework meant to improve the economic assessments of drought risk reduction approaches. The results can be useful to assist practitioners in their decision planning of drought risk management, and subsequently carrying out the most fitting drought interventions.

METHODS

The methods used in this review paper consist of two different elements. Firstly, a systematic literature search was carried out 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 should be taken into account 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.

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 articles that related to the queries "Agriculture" AND "Drought" AND ("Adaptation" OR "Mitigation") were identified. This resulted in a preliminary list of 4243 articles. After removing duplicates, the list consisted of 2025 articles. Building on the initial query, inclusion criteria were formulated 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" or "strategies" in their abstract/title/keywords were excluded. This decreased the selection of articles to 1099. To further filter the selection of records, only articles that refer to "Economic Assessment", "Cost-benefit~", "Cost-effective~", and "Multi-Criteria~" were extracted from this list. 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. Aside from scientific publications, two reports were also found in grey literature. In total, 14 different studies will be analysed in this review paper as shown in Table *1*. The process of the systematic review is depicted in Figure 1.

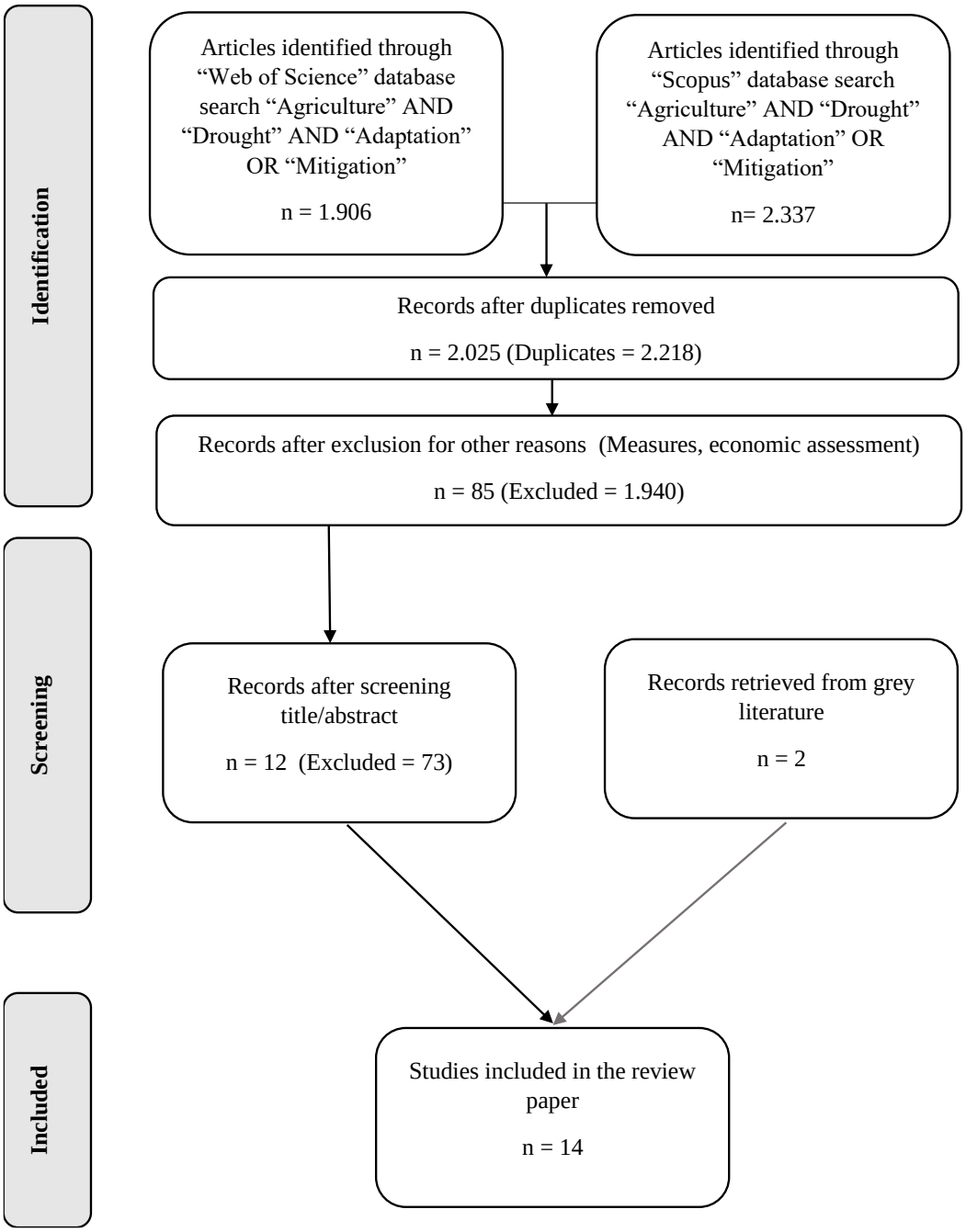

Figure 1. Flowchart of record search and selection. Adapted from Page, et al. [34]

Table 1. Included records

Record	Title	Source	Journal
1	*Marginal Abatement Cost Curves for Water Scarcity Mitigation under Uncertainty*	[35]	Water Resources Management
2	*Cost–benefit analysis of climate change adaptation measures in Bosnia and Herzegovina*	[36]	Euro-Mediterranean Journal for Environmental Integration
3	*Risk-Based Assessment of Drought Mitigation Options: The Case of Syros Island, Greece*	[37]	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*	[38]	Sustainability
5	*Adaptation strategies for water supply management in a drought prone Mediterranean river basin: Application of outranking method*	[39]	Science of the total environment
6	*How can irrigated agriculture adapt to climate change? Insights from the Guadiana Basin in Spain*	[40]	Regional Environmental Change
7	*An Economic Assessment of Local Farm Multi-Purpose Surface Water Retention Systems under Future Climate Uncertainty*	[41]	Sustainability
8	*The implications of drought and water conservation on the reuse of municipal wastewater: Recognizing impacts and identifying mitigation possibilities*	[42]	Water Research
9	*Coping with drought: Lessons learned from robusta coffee growers in Vietnam*	[43]	Climate Services
10	*Costs and benefits of climate-smart agriculture: The case of the Dry Corridor in Guatemala*	[44]	Agricultural systems
11	*Understanding the economics of climate adaptation in Trinidad and Tobago*	[45]	/
12	*Ethiopia Drought Risk*	[46]	/
13	*Evaluating Water Infrastructure and Agriculture Practices for Drought Adaptations in East Africa: A Combined Hydrological and System Dynamics Approach*	[47]	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*	[48]	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, as explained in the following section, apply to the assessment of 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.

Assessment criteria

When planning for climate adaptation, it is important to assess and select the different possible measures [28, 49, 50]. Different measures can be selected and evaluated through various approaches, depending on context-specific objectives. Out of the recommendations made by the UNFCCC [28], several criteria on which the different assessment methods can be evaluated were derived. 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	Short description	Sources
Impact/Vulnerability analysis	Impact and vulnerability analyses aim to discover drought's past and possible 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.	[21, 23, 28, 51, 52]
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.	[22, 28, 51]
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.	[19, 24, 28, 53, 54]
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.	[28]
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.	[22, 28, 55]
Viability of short- and long-term measures in a broad context	When assessing possible 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.	[28]
Sensitivity analysis	Sensitivity analysis needs to be carried out to determine how the output changes if individual key variables (such as the discount rate) are changed.	[28, 56]

These seven criteria provide an indication of which elements should be considered when performing the economic assessment of climate adaptation measures. However, each assessment should still be carefully planned, depending on the local context. 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.

RESULTS

Table 3 gives an overview of how the different assessments carried out in practice measure up to the criteria. This intuitive overview depicts how the studies in practice score per criterion. Per record, the country where the research was carried out is also included. While the records are few, the geographical spread is relatively 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 of short - /long-term measures in the broad context	Sensitivity analysis
1	Sjöstrand, et al. [35]	Sweden	MACC	0	+	0	-	-	0	++
2	Cupac, et al. [36]	Bosnia & Herzegovina	CBA	-	-	0	-	-	0	-
3	Giannikopoulou, et al. [37]	Greece	CEA	++	+	-	+	-	-	-
4	Azorin and Garcia [38]	Spain	CBA	-	-	-	0	-	+	-
5	Kumar, et al. [39]	Spain	MCA Outranking	0	+	+	+	0	+	-
6	Varela-Ortega, et al. [40]	Spain	Economic Hydrological Modelling	+	+	0	0	-	0	-
7	Berry, et al. [41]	Canada	Dynamic Simulation Model	+	-	+	0	+	+	+
8	Tran, et al. [42]	United States	CEA	-	-	0	+	-	0	+
9	Byrareddy, et al. [43]	Vietnam	Comparative Assessment	0	0	-	+	-	-	-
10	Sain, et al. [44]	Guatemala	CBA	-	+	+	0	-	0	+
11	Inter-American Development Bank [45]	Trinidad & Tobago	ECA, Damage Function	-	-	-	0	-	+	+
12	Waldschmidt, et al. [46]	Ethiopia	ECA, CBA	++	+	+	+	0	0	-
13	Agusdinata [47]	Ethiopia, Kenya, Somalia	CEA	+	-	-	0	+	0	-
14	Mutenje, et al. [48]	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 Change
- = 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.

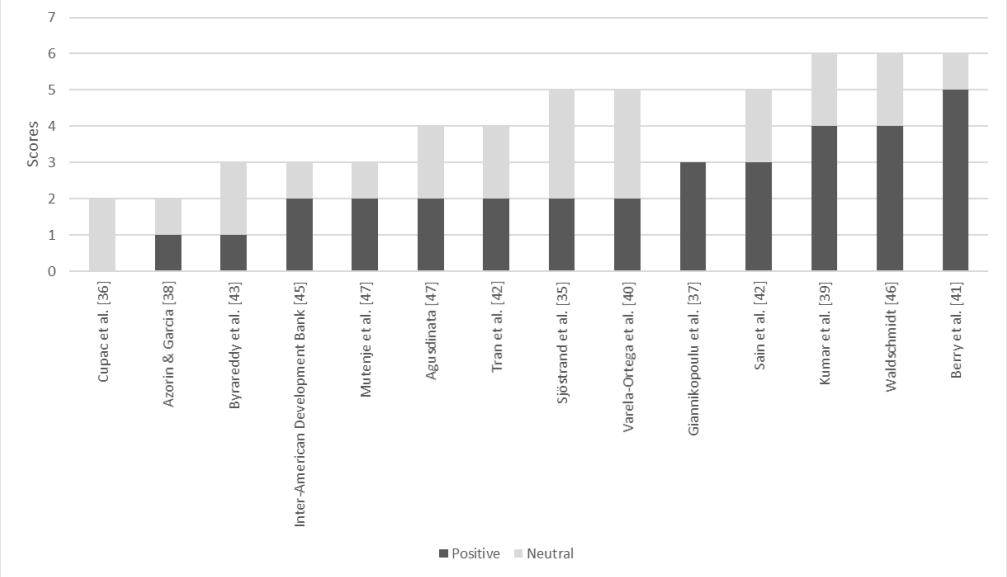

Figure 2: Positive and neutral scores per record

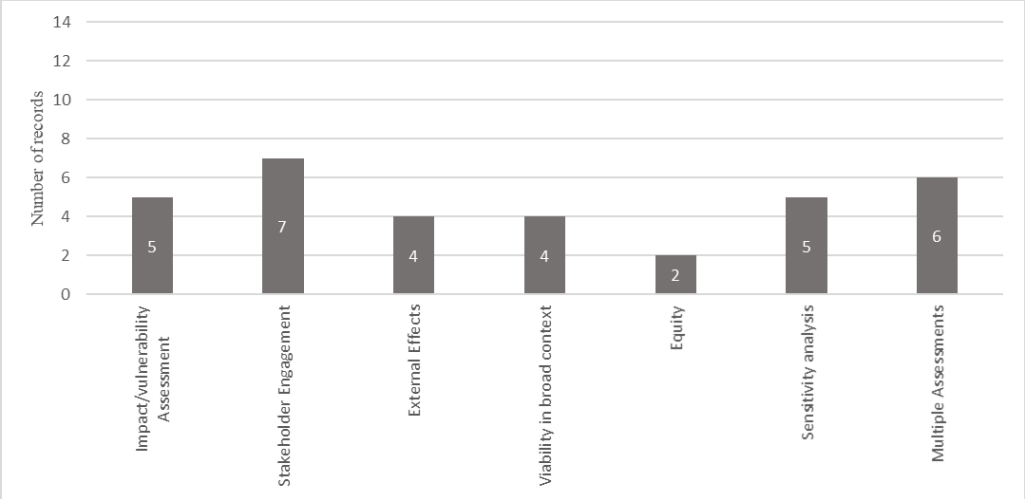

Figure 3. Positive scores per criterion

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. 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. However, the criteria are sufficiently broad to the extent that they can be interpreted over various climate hazards and assessment methods. 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.

While seven different criteria are identified, it is important to note that this is not an exhaustive list. These criteria are merely intended to remind the assessor of different elements that need to be considered to avoid underestimation of the actual costs and benefits of the project. 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. Furthermore, these criteria are relatively 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 Applications is developed based on the different criteria, to aid practitioners in their research.

Impact/vulnerability assessment

Impact and vulnerability assessment is a crucial aspect of climate adaptation planning, as well as of drought risk management [23]. 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 [21, 57]. 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 [4]. Economic assessments often fail to take into account these vulnerability aspects, focusing solely on the monetary impact and underestimating the environmental or social effects [52]. The inclusion of proactive vulnerability assessments can help in designing the appropriate drought risk reduction approaches [58].

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. [37] and Waldschmidt, et al. [46] 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-centred) 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 [21]. 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, than not addressing vulnerability at all [46, 47]. Impact and vulnerability assessments should always consider the local context. While no universally applicable methods can be recommended, these elements need to be taken into account to avoid the exclusion of important results [58].

Stakeholder engagement

Engaging stakeholders in the assessment process can lead to various benefits [28]. They can be an important source of information and allow validation of local results. 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 [24, 57]. 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. [44], Sjöstrand, et al. [35], Varela-Ortega, et al. [40] and Waldschmidt, et al. [46]. Also important is 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 [51].

External effects

When assessing the impact of drought risk reduction approaches, it is crucial to include externalities. Besides the advantage of increasing resilience to drought, these approaches can have socio-economic co-benefits which occur even without the presence of drought [19, 26]. These can be seen as “no-regret” options. Aside from these co-benefits, ancillary effects can also include co-costs [54]. Not including externalities in the assessment of the measures can lead to incomplete results [24]. These are often difficult to quantify. A small part of the reviewed papers attempted to do so, each in a different manner. Kumar, et al. [39] assessed externalities in a broad sense through the use of indices related to environmental stress. Waldschmidt, et al. [46] 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. [41] and Sain, et al. [44] 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 reduces the bias towards the value of ecosystems present [54].

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 [28]. An example of a study relying on a single assessment is that of Cupac, et al. [36], 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. [48] 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 NPV and IRR were calculated, but household characteristics that influenced the likelihood of implementation were also identified. Carrying out 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.

Equity

Distributional effects are often not considered when assessing drought risk reduction approaches, as shown in Table. 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 [28]. Economic assessments should address the equitability of the cost and benefit distribution of different measures [54]. 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 [47] 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. [41], 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. This can improve the implementation of drought risk reduction approaches greatly.

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

The results of the economic assessment of drought risk reduction approaches can provide 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 the broad development and planning context [28]. Often the assessment and implementation of measures are still too focused on small-scale, sector-specific, short-term risks [4]. Considering the broad development and planning context allows for the sustainable upscaling and replication of drought risk reduction approaches [51]. 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 [39], taking into account the impact of the measure beyond the own sector [41] or making recommendations on how policies should change to increase the viability of the assessed measures [38]. While various records consider the broad context to some extent, this is often still limited either in timescale or in scope. 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.

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 [28]. 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 carried out. The studies of Tran, et al. [42] and the Inter-American Development Bank [45] 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 [41]. The paper by Sjöstrand, et al. [35] both 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.

Results

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. [41] 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.

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, including frameworks on how to support national policies on this subject [21-23]. Frameworks or guidelines on how to reliably carry out 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 Change framework (ECA) or the triple dividend of resilience framework [26, 59]. The ECA framework is more widely used for national policies. Yet following this framework does not automatically result in reliable outcomes. This is illustrated by the difference in the scores of Waldschmidt, et al. [46] and Inter-American Development Bank [45] on the seven criteria, who both follow the ECA framework.

The criteria used in the current review paper are intended to distinguish important 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 developed to aid practitioners in the economic assessment for drought risk-reducing applications. 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 Applications (FEADRRA) depicted in Figure 4 will be explained briefly.

1. **Impact and Vulnerability Analysis**

The implementation of an impact and vulnerability analysis is crucial. A baseline scenario without measures applied 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 e.g.) and water (availability), estimated under different climate scenarios. 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.

2. **External Effects**

An important factor to consider is the existence of external effects of measures, such as ecosystem benefits. Since these external benefits are often not considered in the investment decision, the investment option seems less attractive than it is. It is crucial to identify both the private costs and benefits of an investment decision and the external costs and benefits since the latter can affect society as a whole. Identifying these external effects is important to set up policy measures that allow for the internalisation of the ancillary costs and benefits. Their inclusion can greatly affect the results.

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. E.g., measures that might not be beneficial for a single farmer, could improve food security in the long term.

4. **Equity**

Once the outcome is estimated, it is important to study which actors will bear the costs and benefits of the measure. An equitable distribution of the costs and benefits needs to be made to improve the probability of implementation.

5. **Multiple Assessments**

To consider as many relevant objectives and context-specific factors as possible, different indicators and, if the budget and timeframe allow it, different methods of economic assessment should be applied. This will improve the reliability of the investment decision.

6. **Sensitivity Analysis**

To further improve their reliability, sensitivity analysis should be applied to address the various types of uncertainty present in climate change adaptation and disaster risk management.

7. **Stakeholder Engagement**

One of the most important criteria to check is engaging stakeholders during the economic assessment. This will improve the implementation of the different measures, as well as provide the decision-maker with important local information.

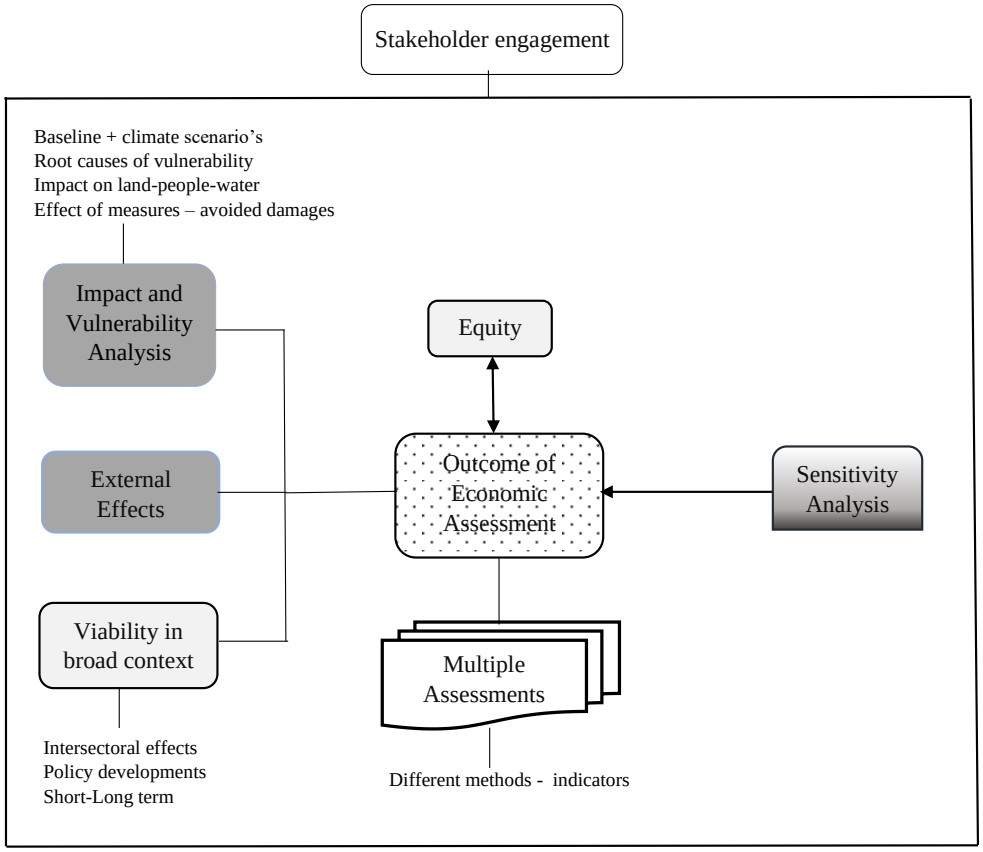

Figure 4. Framework for Economic Assessments of Drought Risk Reduction Applications – FEADRRA

The different described criteria are categorized further by colour 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 coloured dark grey. Those criteria that aid the implementation and distribution of the different measures are coloured 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 coloured with a grey gradient. Lastly, those criteria that span all three categories are depicted in white. This categorisation 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 should first focus on the impact and vulnerability analysis. This will provide them with a preliminary assessment. When more means are available to researchers, they should 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. 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.

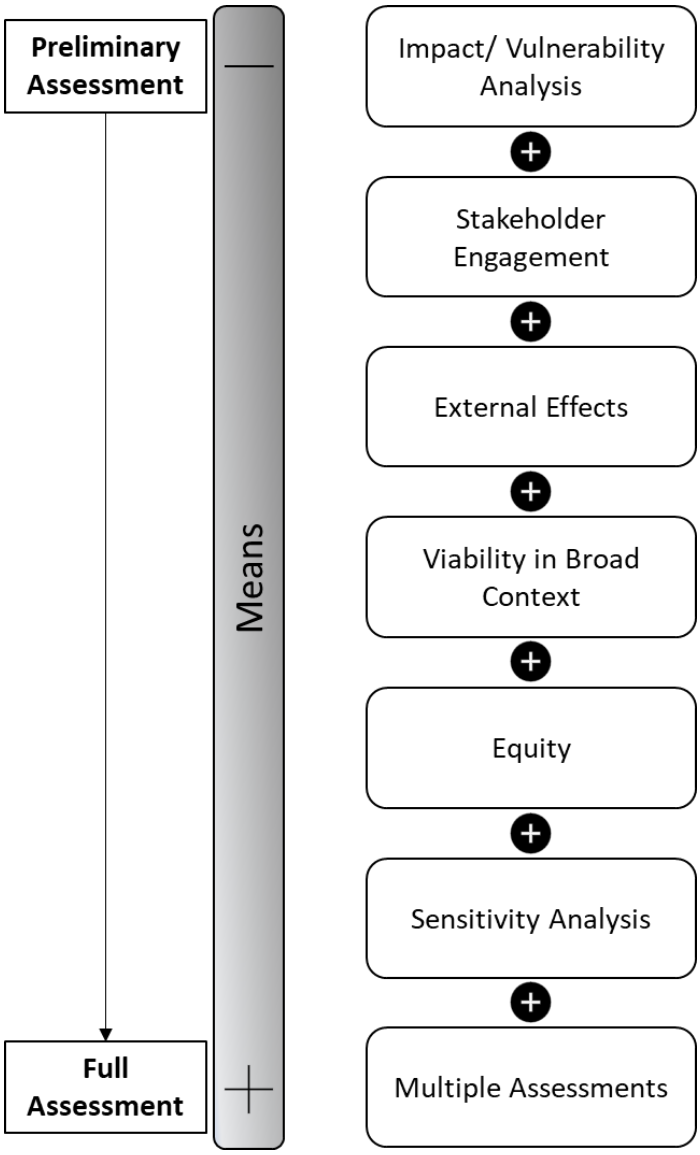

Figure 5: Implementation order of criteria

CONCLUSION AND LIMITATIONS

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 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 and grey literature search resulted in a total of 14 relevant records that performed a type of economic assessment of drought risk reduction approaches. This limited number of records that fit the field of interest provides a first indication that there is sparse information available on this specific topic. As shown in Table *3*, the studies have a high geographical spread as well, which implies 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 Applications (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.

Several limitations are present in this review paper. First, very few studies that fit the field of interest were found. 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 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. Thirdly, most academic reports were investigated in

this paper. It is possible that in operational drought risk management the applied economic assessments are even less comprehensive than discussed here. 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 tested in practice. It is the intention of the author to translate the FEADRRA into practice in future research.

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