Valuing climate services: Socio-Economic Benefit studies of weather and climate services

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Valuing climate services: Socio-Economic Benefit studies of weather and climate services in South Asia

Summary

- This publication is intended to help National Meteorological and Hydrological Services (NMHSs) and other providers of weather and climate services (WCS) develop a broad understanding of the methods for evaluating their socio-economic benefits (SEBs). The document is primarily intended for NMHSs, but will also be of use to other organisations with an interest in evaluating weather and climate services.
- The publication was prepared as part of the Asia Regional Resilience to a Changing Climate (ARRCC) Met Office Partnership (MOP). The ARRCC MOP programme is a four-year programme running from 2018-2022, which aims to strengthen weather forecasting systems across Asia. The programme will deliver new technologies and innovative approaches to help vulnerable communities use weather warnings and forecasts to better prepare for climate change.
- The methods presented here are based on the WMO's 2015 report on Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services. The purpose of the WMO 2015 report was to provide detail on how to pursue SEBs to ensure efficient financing for and within NMHSs. The ARRCC MOP report presents a condensed version of each of the SEB methods detailed in the WMO report. A brief summary of each method is presented, along with advantages/disadvantages of using each method, and examples of how each method has been applied to WCS evaluation.
- ARRCC MOP will work with partners in one of our focus countries (Afghanistan, Bangladesh, Nepal and Pakistan) to support the implementation of this guidance in an NMHS.

Contents

Acronyms

AAS	Agricultural Advisory Service
CV	Contingent Valuation
EWS	Early Warning System
GFCS	Global Framework for Climate Services
IPCC	Intergovernmental Panel on Climate Change
NMHS	National Meteorological and Hydrological Services
RV	Revealed Preferences
SEB	Socio-Economic Benefit
WCS	Weather and Climate Service
WMO	World Meteorological Organization
WTP	Willing to Pay
WTA	Willing to Accept

1. Why value weather and climate services?

The use of meteorological, hydrological, oceanographic and related information can deliver enormous benefits to society by enabling individuals, households, organisations, businesses and governments to make informed decisions that mitigate the impacts of weather and climate (WMO, 2015). In turn, this can have substantial social and economic benefits and contribute to sustainable development. The importance of weather and climate services (WCS) was emphasised in the IPCC's 2018 Special Report on Global Warming of 1.5°C, which recognised the critical role climate services can play in decision-making across all scales. However, despite the growing importance of WCS there remains a lack of common understanding on their value to economy and society (Allis et al., 2019, Hewitt et al., 2012).

Valuing the socio-economic benefits (SEBs) that result from WCS is an important part of justifying investment in the provision and delivery of climate and weather information. For example, it has been estimated that with a relatively modest spend around 1 billion US per year, upgrading early warning systems across all developing countries in the world would result in between $300 million and $2 billion per year of avoided asset losses, save around 23,000 lives per year, and generate additional benefits of up to $30 billion a year (Hallegatte, 2012). This is a benefit-cost ratio of between 4 and 36. Demonstrating the value of WCS is particularly important for services provided by National Meteorological and Hydrological Services (NMHS) where public funding pays for activities (Bruno Soares et al., 2018, WMO, 2015). In order to compete for scarce public resources, NMHSs may have to demonstrate that the benefits of their services are significantly larger than the costs to produce and deliver them (WMO, 2015). Although the cost of modernising NMHSs will be considerable, the benefits are likely to be much higher (Rogers and Tsirkunov, 2013). Valuation studies can also contribute to tailoring services to end users; justification of pricing for bespoke products, such as seasonal forecasts; informing adaptation decisions where multiple adaptation options exist; and promoting the benefits of WCS to new users (see, Bruno Soares et al., 2018)

The services provided by NMHS offer a wide range of benefits to society, many of which are intangible and hard to quantify (Lazo et al., 2008). Some of the key outcomes of WCS, such as a reduction in the number of hurricane deaths following an early warning, or an increase in food security following delayed planting in response to a seasonal forecast, cannot be immediately observed in the marketplace. As such these goods and services are referred to as **non-market**. In addition to not being traded in markets, WCS can be characterised as public goods (Hewitt et al., 2012) as their use cannot be restricted to one individual. This 'free-rider' problem is a fundamental problem associated with 'non-excludable' public goods that are created by private action (Tompkins and Eakin, 2012). If people know that forecasts and information are provided for free, they may not be willing to pay for their creation. This makes demonstrating the value of WCS all the more important.

2. Planning an evaluation study

In the WMO's 2015 report, *Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services,* it is assumed that NMHSs are unlikely to conduct their own evaluations of WCS. Instead, it suggested that most NMHSs will commission the work whilst providing management oversight for the study. However, there may be some cases where NMHSs do in fact undertake their own evaluations in-house. Regardless of who conducts the evaluation, it is essential to plan the SEB study from the outside. This helps to determine resource needs including the type of expertise required, the type of data needed, funding and time allocation.

Planning the evaluation can be categorised into three broad stages (Table 1); pre-evaluation, evaluation, and post-evaluation.

- The **pre-evaluation stage** sets out the aim and scope of evaluation, identifies the method to be used, and prepares the resources for the evaluation, including expertise, budget, and timelines.
- The **evaluation stage** begins with the identification and analysis of relevant stakeholders. The baseline is then established to provide a point of reference from which changes can be evaluated. Using an evaluation method (i.e. stated preference, revealed preference, economic decision modelling, avoided costs, benefit transfer or participatory methods) the full range of benefits and costs of the WCS are identified. Finally, all omissions and biases are listed.
- The **post-evaluation stage** focuses on communicating results to decision makers and stakeholders, as well as possible monitoring and evaluation of uptake and use of key findings.

The focus of the remainder of this document is on the methods that will be used to inform the evaluation. There are many resources available to help inform other aspects of the evaluation including stakeholder analysis, preparing baselines, developing communication and dissemination strategies and setting up monitoring and evaluation frameworks.

3. Methods for valuing Weather and Climate Services

This section outlines some of the key methods that are used in valuation studies. Many WCS are valued using techniques that are compatible with **Benefit Cost Analysis** (BCA). In basic terms, a BCA is a tool used to analyse decisions in which the costs of a project or an action are subtracted from the benefits. Costs and benefits may be tangible, such as the amount of money expected to be saved as the result of an intervention. They may also be intangible, such as the impact on wellbeing. Because the BCA compares monetary values of benefits and costs, all the items on the cost-benefit list should be assigned a monetary value.

In addition to BCA, SEB evaluations can also use **participatory methods** to gain a deep qualitative understanding of the impact of weather and climate services on end users. These types of studies tend to be influenced by livelihood approaches, vulnerability studies, risk analysis, and gender issues (Tall et al., 2014). Participatory methods can be used alone or can complement other monetary valuations.

Methods can be selected depending on a number of factors including the aim of the evaluation, the type of WCS under examination, the current or intended users of the service as well as budget, time, and available expertise to implement methods (as some methods that reveal more precise data, such as surveys, require significant resources whilst others such as benchmarking and benefit transfer are less resource intensive, but may lack detail) (WMO, 2015). As mentioned earlier, the purpose of these type of evaluations can cover a number of underpinning reasons such as the need to justify public expenditure in the provision of WCS, to help gain support for improving existing services or simply to raise awareness of the benefits of using WCS. In addition, the type of WCS under examination will also

Table 1: Steps to be considered before, during and after evaluation

Pre-evaluation		
Identify aim and scope of evaluation	What is the WCS that will be evaluated?	Include specifics on how the WCS is organised, including who produces the information, who uses it, as well as the aim of the WCS.
	Is this a new or existing WCS?	This will affect the type of evaluation to be conducted. An ex-post evaluation collects data to assess the actual or realised SEBs of a WCS. An ex-ante evaluation collects data during the design or implementation of a WCS to guide further development of that service.
Identify the method(s)	Which is the most suitable method for conducting the evaluation?	Common methods to evaluate WCS include: contingent valuation, revealed preferences, economic decision modelling, avoided cost assessments, benefit transfer, and participatory methods (see Section 3).
Identify resources for conducting the evaluation	Who will conduct the evaluation?	The WMO (2015) assumed that NMHSs are unlikely to conduct their own evaluations and will commission the work. However, there may be some cases where NMHSs do in fact undertake their own evaluations in-house. This will require in house expertise.
	What expertise is required?	The methods presented here require expertise in economics (contingent valuation, revealed preferences, benefit transfer, avoided costs), computer modelling (economic decision modelling), and qualitative research (participatory methods).
	What financial resources are required?	Financial resources are likely to depend on: the method used and type of expertise required; the point at which the evaluation will be conducted; as well as the length of the evaluation (e.g. will there be a long period of monitoring and evaluation).
During evaluation		
Stakeholder analysis	Who is interested or influential in the outcome of the evaluation?	The WMO (2015) suggest the following groups as key stakeholders: Governing decision makers (ministry, treasury, boards of directors, and the like); NMHS leadership; Sectoral ministries and partner agencies; External funding agencies; user communities. Stakeholder identification/analysis tools can help identify relevant stakeholders. Collaborating with stakeholders from the outset helps generate relevant findings.
Establish the baseline	What is the current situation in the location under study?	The current/status quo situation is the baseline. This provides a point of reference from which changes can be evaluated. In situations where the WCS is already being delivered, the baseline information without the service may be the information provided by another

		NMHS (for example, from a neighbouring country) (WMO, 2015).
Identify the full range of benefits and costs	What are the quantitative benefits and costs of the WCS?	Using the method chosen in the pre-evaluation stage (and detailed in section 3), the analyst will provide quantitative detail of all the all costs and benefits. The benefit cost ratio (BCR) will be determined. The BCR is the relationship between the costs and benefits; a BCR greater than 1 is expected to deliver a positive value. It should be recognised that a benefit cost assessment (BCA) is a complex technique that requires significant expertise in economics. If using participatory methods, it may not be appropriate to quantitatively describe the findings.
	What are the qualitative benefits and costs of the WCS?	Evaluations can also go beyond economic explanations. Qualitative 'narratives of experience' can help provide context to economic valuations, and can also be used on their own.
List all omissions, biases and uncertainties	What are the data gaps, uncertainties and other limitations?	This is important in helping NMHSs and funding authorities understand the limitations due to data issues, funding constraints, and uncertainties inherent in assumptions and future values. Being open about limitations helps build confidence with stakeholders.
Post-evaluation		
Formulate and communicate results to decision makers and stakeholders	What are the key messages?	If the outcome of the evaluation is to be shared with a range of decision makers and stakeholders, it may be necessary to tailor the key message for each audience. Customizing communications can help ensure the relevance and effectiveness of key messages.
	What medium is appropriate for delivering messages?	Key messages should be distributed through the audience's preferred communications channels. These could be established during the stakeholder analysis stage.
Monitoring and evaluation of uptake and use	Will the impact of the evaluation be monitored?	The key findings of the evaluation may be used in various ways (as outline in section 1) including: tailoring services to end users; justification of pricing for bespoke products, such as seasonal forecasts; informing adaptation decisions where multiple adaptation options exist; and promoting the benefits of WCS to new users. To ensure that evaluation has maximum impact, it may be necessary to design a M&E strategy.

influence the choice of methods to be used. For example, a service providing a weather forecast will be very different from a service focusing on long-term climate change projections given the temporal scale of the information provided and how that can be evaluated in terms of the socio-economic benefits to be yielded.

The type of end user will also influence the type of method used. A service that provides information to a specific group of users at a local level will require a different set of evaluation methods to a service that is available, for example, through an NMHS website and aims to reach a significant number of users (Bruno Soares and Buontempo, 2019). As such, the spatial scale of the service and the target users it aims to reach are also factors that need to be considered. Some evaluations may include all stakeholders with a role in the climate services value chain, from production, co-development through to use at the local level (WMO, 2018).

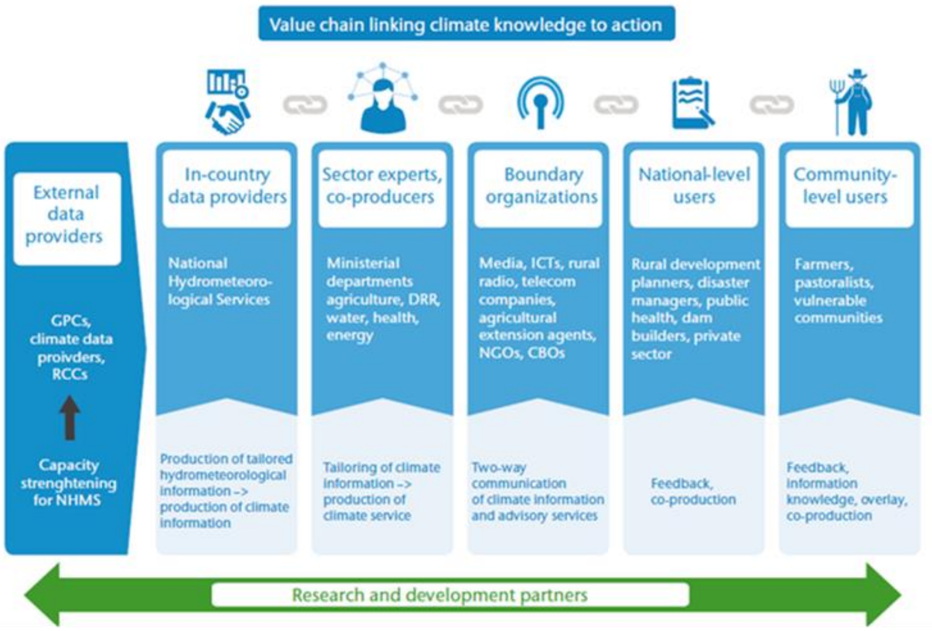

Figure 1. National value chain for climate services. Source: WMO, 2018.
(CBO = community-based organization; GPC = global producing centre; ICT = information and communications technology; NGO = non-governmental organization; RCC = Regional Climate Centre)

Another aspect that one should consider when thinking of pursuing this type of evaluation is the stage of development of the service. Evaluating the potential socio-economic benefits of a WCS that has not yet been developed will be based on a set of assumptions and techniques that may be very different from those used to assess a service that is already running and being utilised by others. In this context, it is important to highlight two different types of evaluations that can be pursued.

On the one hand, we can perform ex-ante analyses which are normally based on the expected or hypothetical benefits associated to a service (which may or may not already exist) and, on the other hand, the ex-post evaluations which are based on observed outcomes and benefits of using a service and thus require for the service to be fully operational (Bruno Soares et al., 2018).

The main methods (detailed in Table 2, also see Appendix 1) used to evaluate WCS are: (1) contingent valuation; (2) revealed preferences; (3) economic decision modelling; (4) avoided costs; (5) benefit transfer; and, (6) participatory methods. The following pages provide information about the following valuation techniques

Table 2: Methods used in SEB evaluations of WCS

Method	Description
Contingent valuation	Uses surveys to determine how much respondents would be willing to pay (WTP) for a specific weather or climate service.
Revealed preferences	Measures consumers' preferences for a WCS by observing their purchasing behaviour.
Economic decision modelling	Uses models to examine the decisions taken when people have access to WCS and when they do not
Avoided costs	Determines to economic costs that are avoided as a result of weather or climate information
Benefit transfer	Takes the findings of an original evaluation of WCS and applies them to a new geographic or policy context.
Participatory methods	Employees a range of participatory methods to produce a deep qualitative understanding of the benefits of WCS on end users

3.1. Stated preference - Contingent Valuation

What is contingent valuation?

Contingent Valuation (CV) is a method of estimating the value that a person places on a good by asking them directly. It is one of the most widely used techniques to value non-market goods such as water, air, soil and biodiversity (Carson et al., 2001). CV is a **stated preference technique** where people are asked to report their willingness to pay (WTP) for a particular good, or their willingness to accept (WTA) giving up a good for compensative. The CV approach is in contrast to the revealed preferences technique (see section 3.2), which infers the value of a good from actual or observed behaviours.

In the CV method, respondents are presented with information, usually as part of a survey (e.g. Amegnaglo et al., 2017, Loomis et al., 2000, Anaman and Lellyett, 1996). They are then asked to indicate how much a good or service is worth to them. There are different ways to do this. **Open-ended CV surveys** may ask respondents to state directly what they would be willing to pay for a good without specifying an amount (e.g. Alvarez-Farizo, 1999). **A referendum CV** provides respondents with specified amounts that may vary across respondents. And, a **payment-card CV** gives the respondent a series of monetary values and ask them to indicate which represents the maximum they would be WTP (Lazo, 2015). More recently, **choice experiments** have been used to estimate WTP (Lazo, 2015). In choice experiments, respondents are given two (or more) alternatives against the status quo (existing scenario) and are asked to state which they prefer. As each alternative has different attributes and prices, WTP can be inferred by the analyst (Adamowicz et al., 1998)

The use of CV studies is heavily debated. With specific regard to forecasts, Stewart (1997) argues that CV studies only provide an idea how useful forecasts might be rather than their actual value as there is no attempt is made to show if forecasts are actually used. More broadly, concerns exist around the validity and reliability of CV results (Hausman, 2012). Amoah et al. (2019) point out three issues with CV studies: (1) hypothetical bias, (2) the divergence between WTP and WTA (3) income effects. **Hypothetical bias** occurs when respondents' stated behaviour is different to their actual behaviour. Respondents tend to overstate their economic valuation of a good by about two or three times (Murphy et al., 2005). The **divergence between WTP and WTA is** widely documented in behavioural economics. Individuals usually require a greater amount of money for giving up a good (WTA) than they would be willing to pay for it (Tunçel and Hammitt, 2014). Finally, **income effects** are the change in stated WTP for a good associated with a change in income defined (Horowitz and McConnell, 2003). Understanding income effects is a good indicator survey validity as a lack of positive income effect may indicate that respondents did not account for budget constraints when making hypothetical choices (Schläpfer, 2006).

Carson et al. (2001) suggests that the debate around CV may reflect the large sums of money at stake in major environmental decisions and a general distrust in surveys by economists. However, they suggest that many of the issues highlighted above can be overcome with careful study design and implementation. Carson and Groves (2007) argue that ensuring surveys are 'consequential' increases validity. In other words, if the respondent believes their responses may influence action, and they care about those actions, they should treat the survey questions as an opportunity to influence change. One way to test consequentiality is to simply ask the respondents themselves through the development of respondent-based self-assessed indicators (Nepal et al., 2009).

Is contingent valuation the correct tool for my study?

Advantages of contingent valuation:

- Estimates use and non-use values (non-use values relate to the feelings people have about goods)
- Can value goods that are not already being provided

Limitations of contingent valuation:

- Time intensive and expensive to implement
- Potential issues with hypothetical bias, the gap between WTP and WTA and income effects
- Challenging to frame survey questions that ensure validity

Case study of contingent valuation

Contingent valuation and choice experiments were used to estimate the WTP for an improved early warning system (EWS) in Bangladesh (Ahsan et al., 2020). Using random sampling, respondents from 490 households across three districts (Khulna, Satkhira, and Barguna) were selected to perform a choice experiment. A questionnaire captured information from the respondent on three key areas: (1) socio-demographic and asset portfolios; (2) exposure to and experience of hazards; and, (3) experiences of existing early warning services. Respondents were also issued with a choice card which gave three alternatives to the status quo. Each alternative consisted of four attributes: (1) precise landfall times of a cyclone and possible impacts; (2) number of daily radio updates; (3) voice messaging advisories in local dialects via mobile phones; and (4) a bidding price (i.e. cost) (see Table 3). Respondents were asked to select their preferred alternative from the card, considering the cost component of that alternative. Results show that the average WTP for an improved EWS was BDT 468 (≈US$ 5.57) per year. Respondents were WTP the most for improvements in accuracy, followed by receiving local dialect mobile phone voice messages. They were WTP the least for increased frequency of radio forecasts.

Table 3. Example of a choice card for the CV method

Attribute (S)	Imagining	Status Quo	Improvement Level 1	Improvement Level 2	Improvement Level 3
Precise time of cyclone landfall with possible impacts		Before 10 h/after 12 h (no impact is presented)	Before 5 h/after 7 h (with possible impact)	Before 4 h/after 6 h (with possible impact)	Before 2 h/after 4 h (with possible impact)
Radio Forecast		5 Times a day	8 Times a day	12 Times a day	24 Times a day
Voice Message in Local Dialects		None	4 Times a day	8 Times a day	12 Times a day
Bidding Price		0	BDT 350 (US$ 4.17)	BDT 700 (US$ 8.33)	BDT 1000 (US$ 11.91)

Source: Ahsan et al. (2020).

Box 1: Other examples of studies using contingent valuation

Contingent valuation has also been used to:

- Assess the economic benefits of seasonal climate forecasts in Benin, West Africa based on a survey of 354 maize farmers. The vast majority (83%) of farmers were WTP around $19USD for seasonal climate forecasts. At the national level, the average annual economic value of seasonal climate forecasts was around USD 66.5 million dollar at the national level (Amegnaglo et al., 2017);
- Determine WTP for a weather information service tailored to the cotton industry in Australia. Average annual WTP for the service was about US$175 during a drought, or US$ 204 during a period of good rainfall (Anaman and Lellyett, 1996);
- Investigate the value of improved weather forecast information to farmers in Mozambique. Results showed a mean annual WTP of about US$ 0.09 per individual. Farmers who had experienced more weather related losses in the past or who already used forecasts were willing to pay more than others in the study (Lazo, 2015).

3.2. Revealed preferences

What is the revealed preference method?

The revealed preference (RP) techniques assume that people's preferences for environmental goods and services can be **revealed by examining their actual behaviour.** RP techniques measure how much money is actually spent on a WCS by using available market data. The **averting behaviour method** examines values based on spending that reduces personal risk and is best applied to activities that reduce the impact of environmental events on human health (Barbier et al., 2009). The **travel cost method** uses empirical data on tourist behaviour to determine whether people pay more to visit sites where services such as forecasts are available. And **hedonic pricing**, best applied where the impacts of climate change are less extreme, infers the value of a non-market good or service from prices of related goods that can be traded. For example, factors such as distance of amenities, a great view, and proximity to polluting activities can affect the price of land and property, so the value of these factors can be estimated from land and property prices (Hecht, 2013).

Like with stated preferences techniques, RP have their weaknesses. For example, when a consumer has complete information, their choice of one option over another conveys preference. But consumers do not always have complete information so are not always aware that other alternatives are available (Caplin and Dean, 2011). Another criticism is around the assumption that preferences remain constant over time. Crucially, there have been very few studies of RP within climate services that can be used to support the design of new evaluations. To some extent, these weaknesses can be overcome by combining RP studies with CV studies (see, Whitehead et al., 2008, Andersson, 2007). It may also be possible to learn from RP studies in other fields such as ecosystems services.

Is the revealed preference method the correct tool for my study?

Advantages of the revealed preference approach:

- Higher acceptance rate than stated preference techniques
- Can be combined with stated preference techniques to increase validity and overcome limitations

Limitations of the revealed preference approach:

- Reliance on historic data that may be missing
- Must consider how to account for changing tastes
- Can only be used where the value people place on a non-market outcome can be deduced from their behaviour — this generally rules out using the methods to quantify non-use values
- Few studies within weather and climate services

Case study of the revealed preference method

As few studies of RP exist for weather and climate services, it may be possible to learn from the use of RP in ecosystems services. Rasul (2009) estimates the costs and benefits of four major land-use systems in the Chittagong Hill Tracts of Bangladesh. These are: annual cash crops; horticulture;

agroforestry; and, farm forestry. The study combined revealed and stated preference methods to estimate the monetary value of the environmental services generated by different agricultural practices. The research team sampled 304 farm households using a standard questionnaire, followed by interviews on spending, including the volumes and prices of inputs and outputs. The study showed that when the environmental impacts of farming were ignored annual cash crops were the most profitable crop. However, in terms of environmental and economic sustainability, annual cash crops were the least desirable land use option as they decreased natural capital through high rates of soil erosion and biodiversity loss. A key finding of the study was that in order for farmers to change their behaviour in response to new information, support services, including long-term credit, knowledge transfer, and information on adopting new practices and techniques may need to be adopted.

3.3. Economic decision modelling

What is economic decision modelling?

Within NMHS, economists use models to determine the value of information for decision makers (through decision theory) as well as to determine how of NMHS can impact local, regional or national economies from either an ex-ante perspective (through the use of equilibrium modelling) or an ex-post approach (through the use of econometric modelling) (WMO, 2015).

Decision theory analyses the decisions that people or institutions take when they have access to NMHS services and when they do not. For example, decision theory analysis has shown that with probabilistic weather foresting, the Washington State Department of Transportation could save 50% of their budget by icing roads at the correct time and avoiding road closures (Berrocal et al., 2010). It is important to note that decision models should only be used when the choice of a decision maker cannot affect an outcome for another decision maker (WMO, 2015). For example, a single farmer who uses seasonal forecasts will have little impact on regional production and would therefore have little impact on overall price (Rubas et al., 2006).

Criticisms of decision theory are often based on the theory's two core assumptions. First, decision theory assumes that that the decision maker makes decisions based solely on the effect of the decisions on their payoffs (Rubas et al., 2006). This assumes that agents are rational and will always choose the option that maximizes their utility. This view has long been challenged by those who say people's behaviour is more complex than this and is influenced by personal thoughts and feelings that seem irrational (see, Ajzen, 2011). The second assumption that agents have some level of climate knowledge that, in the absence of updated climate information, they use to make their choices (WMO, 2015).

Econometric modelling can be used to understand the effect of independent variables (e.g., price, age or income) on a dependent variable (e.g. the value of a climate service) (WMO, 2015). Regression analysis is the most common form of econometric modelling. A classic example of this Anaman et al. (1997) who conducted an econometric analysis of the impact of aviation weather forecasts on fuel expenditure for the Australian based Qantas Airways. The study showed that the airline saved between US$19 million and US$30 million a year by only carrying extra fuel based on weather forecasts, following the abandonment of a mandatory requirement for aircraft to carry extra fuel.

More recently, Lechthaler and Vinogradova (2017) applied a Random Utility Model to choice experiment data from coffee farmers in Peru in order to assess the value of climate services in the agricultural sector.

Criticism of economic modelling often centre on the strength of correlation between two variables that maybe appear to be related but are in fact causally unrelated. In fact, a high correlation does not necessarily imply a causal relationship. However, correlations can reveal potential relationships that should be investigate with further analysis (Blalock, 2017). One way to do this is through the use of participatory methods with end users outlined in section 3.6.

Equilibrium modelling examines changes in supply and demand and the effect on price associated with use of NMHS. Unlike decision theory, equilibrium models recognise that the choices of different decision makers are interlinked (Clements et al., 2013). For example, equilibrium models can be used to aggregate changes in farmers' production in response to forecasts. They have also been used to examine the effect of ENSO-based climate forecasts on the agricultural sector using a previously developed model of U.S. agricultural production (see Rubas et al 2006).

Is economic decision modelling the correct method for my study?

Advantages of economic decision modelling:

- Can be relatively simple to perform depending on model used
- Useful to examine decisions at different scales, from household to institution

Limitations of economic decision modelling:

- Time and data intensive
- Expensive to implement
- Requires significant expertise
- Decision theory can only be used when the choice of a decision maker cannot affect an outcome for another decision make
- Relationships between variables may need to be probed further

Case study of economic decision modelling

The use of perfect and imperfect forecasts of sea surface temperature anomalies (SSTA) in the Equatorial Pacific for potato fertilization management in Chile, South America was examined by Meza and Wilks (2004). SSTAs are a good predictor of seasonal rainfall fluctuations, which can affect potato crops. The researchers examined whether having access to a perfect forecast helped farmers make optimal decisions around planting dates as well as how much fertiliser to apply and when to apply it. With better decision making, farmers may be able to maintain economic returns from farming.

The study used weather modelling, soil-crop modelling and an intertemporal (i.e. time-dependent) economic decision model to assess the economic value of both perfect and imperfect SSTA forecasts. The researchers used the model to examine the effect of different types of climate forecast on farmers' potential willingness to pay for information (i.e. differences in the expected utility obtained using forecasts and expected utility based on climatological information). The model accounted for physical factors (such as type of soil and location) as well as physiological factors such attitude to risk.

The study found that the expected economic value of a hypothetically perfect SSTA was approximately 20 $/ha.

Box 2: other examples of economic modelling

Economic modelling has also been used to:

- Determine success of the United States' National Weather Service (NWS) Heat Watch/Warning System in Philadelphia, Pennsylvania. Using household survey data from elderly respondents regression analysis was conducted to determine lives saved (Ebi et al., 2004);
- Evaluate the economic impacts of ENSO events on a regional water market with and without the use of ENSO information. Results showed that a water management strategy based on transferring water among different groups could potentially increase social welfare by as much as $11.6 million when ENSO information was provided (Liao et al., 2010);
- Show that use of seasonal forecasts in the agricultural sector will affect production, machinery manufacturers, food processors and retailers, and the financial sector (Mjelde et al., 2000).

3.4. Avoided cost/damage assessments (including avoided mortality and morbidity impacts)

What is the avoided cost method?

The avoided cost method evaluates the benefits of improved weather and climate information by determining how the information contributes to avoided asset losses and avoided mortality (lives saved) (WMO, 2015).

Avoided assets losses refer to impacts that have been prevented due to appropriate responses to weather and climate information. In storm prone agricultural societies, loss may be avoided by protecting moveable assets such as livestock, school or office equipment, vegetables or fruit crops (through early harvesting), or by maintaining potentially dangerous trees (depending on lead time) to protect physical infrastructure (Fakhruddin and Schick, 2019). Loss may also be avoided through avoided spending, for example by reducing the number of road personnel who are contracted to deal with heavy snowfall (Frei et al., 2014). A criticism of avoided costs assessments is that they do not capture the use of climate information to improve production or net income. For example, an avoided cost assessment would not reveal details of how a farmer deals with climate variability. Therefore, avoided loess assessments do not give a complete estimate of the benefits from acting on climate information (WMO 2015).

Avoided mortality assessments put a monetary value on lives saved as a result of weather and climate information. The value of a statistical life method (VSL) uses contingent valuation to assess individual willingness to pay (WTP) for small reductions in the risk of dying. The Value of a Life Year (VOLY) is uses WTP for increasing life expectancy by one year. Both methods have been used in weather and climate services, for example, in assessments of the avoided mortality from early heat warning systems (Ebi et al., 2004, Burgess et al., 2014, Chiabai et al., 2018)

Is the avoided cost method the correct method for my study?

Advantages of the avoided cost method:

- Can be applied in ex-post and ex-ante analysis
- Relativity easy to implement

Limitations of the avoided cost method:

- Only represents partial value
- Does not consider benefits of NMHS associated with increase productivity and enjoyment

Case study of the avoided cost method

The avoided losses method has used by the World Bank (Teisberg and Weiher, 2009) to understand the losses that could be have been avoided during 2007's Cyclone Sidr in Bangladesh. Cyclone Sidr, a category 4 storm, killed around 3400 people and resulted in US$1.7 billion worth of damage and the losses would have been greater if improved forecasting and an early warning system had not been in place (Lumbroso et al., 2017). However, the highest evacuation warning was only issued 27 hours before the storm hit (Paul and Dutt, 2010). An advanced numerical weather prediction system could have extended lead times to 5 days, and more accurately identified the areas at risk of heavy rainfall and strong wind.

With greater lead times, and more accurate information about the magnitude and likelihood of impacts, at risk populations could have better mitigated their losses by early harvesting of crops, fish, and shrimp, and by securing household possessions, farm and fisheries equipment, livestock, equipment in offices and schools. It is estimated that with a numeric EWS, combined average avoided annual losses under cyclones and flooding would be US$181m.

Box 3: other examples of the avoided cost assessment

Avoided cost assessment has also been used to:

- Demonstrate the SEBs of a cyclone EWS in Samoa. The authors assessed previous cylone damage and carried out interviews with stakeholders. The results showed that for every USD 1 invested in the EWS, there was a return of USD 6 (Fakhruddin and Schick, 2019);
- Estimate the value of hurricane forecast information to oil and gas producers in the Gulf of Mexico. A 48-hour forecast was estimated at US$ 8.1 million annually in terms of avoided costs and avoided labour (Costello et al., 1998);
- Determine avoided government spending in relation to improved meteorological services for the transportation sector in Switzerland. Improved weather information would result in US$ 56.1 million to US$ 60.1 million in avoided governmental spending. (Frei et al. 2014).

3.5. Benefit transfer

What is the benefit transfer method?

The benefit transfer method applies economic values from a previous study to a new context. The previous study is the 'study site' and the location to which estimates are transferred is the 'policy site'. This method had been widely used to estimate the value of ecosystem services in one location and transfer them to value ecosystem services in a similar location (Costanza et al., 1997, Kubiszewski et al., 2013). There is some limited use of the method in climate services, most notably by Hallegatte (2012) who estimated the potential benefits of providing early warning systems in developing countries based on a study of benefits for similar services in Europe.

The following steps are recommended when conducting benefit transfer (Table 4) (WMO, 2015, EPA, 2014, Lazo et al., 2008):

Table 4: Recommended steps for a benefit transfer

Step	Purpose	
Describe	Describe the issues, including the impacts on the population	
Identify	Existing relevant studies through a literature search	
Review	Review available studies and consider:	
	Quality	Do the original studies use adequate data, sound economic and scientific methods and correct empirical techniques?
	Impacts	Are the expected changes similar in magnitude and type in the study site and policy site?
	Population	(If possible) do both studies have similar locations and populations?
	Differences	What are the cultural and economic differences between locations?
Transfer	Transfer benefits to the new study	
Uncertainty	Make clear all assumptions, judgements and uncertainty	
Report	Report estimates as well as uncertainty	

Benefit transfer relies on the two case sites (the 'study site' and the 'policy site') sharing similar characteristics, including the composition of the community. Importantly, the commodity that is being valued should be identical in both sites (Rosenberger, 2015). The main weakness of this method is there is a high generalization error resulting the difference between the two studies (Rosenberger and Stanley, 2006).

Is benefit transfer the correct method for my study?

Advantages of benefit transfers:

- Relatively simple
- Relatively inexpensive

- Accepted as a suitable method for estimating order of magnitude values for use and non-use benefits, in ex-post and ex-ante analyses

Disadvantages of benefit transfer:

- Can generate potentially inaccurate and misleading results through generalisation
- Limited number of original studies

Case study of the benefit transfer method

Perhaps the best-known example of the benefit transfer for hydro/met services is Hallegatte's (2012) estimation of the potential benefits of upgrading early warning systems in developing countries based on a study of benefits for similar services in Europe. Using existing studies, Hallegatte first estimated the economic benefits of hydro-meteorological information and early warning systems for Europe and concluded that each year this information saves hundreds of lives, avoids between 460 million and 2.7 billion Euros of assets lost through disaster, and produces between 3.4 and 34 billion of additional benefits though optimised used of resources across sectors. The potential for similar benefits in the developing world, where fewer original studies exist, were then assessed.

Hallegatte estimated that upgrading early warning systems across all developing countries in the world would result in between $300 million and $2 billion per year of avoided asset losses. Furthermore, early warning systems would save an around 23,000 lives per year. The analysis considered differences in population, location and climate risk. It also accounts for the state of infrastructure in each country.

Box 4: Other examples of the benefit transfer method

Benefit transfer has also been used to:

- Estimate the value of improved ocean observing data to recreational fishermen in Florida using estimates of WTP for recreational fishing (per fish caught) from existing literature (Weiand, 2008);
- Determine the value of information from improved El Nino forecasting for Coho Salmon fisheries in the US Pacific Northwest. Using estimates from the literature, it was determined that ENSO-based forecasts would result in an annual welfare gain of approximately $1 million (Costello et al., 1998);
- Estimate the value for a number of selected sectors (households, agriculture, energy) from weather services in Switzerland to be in the region of hundreds of millions of United States dollars (Frei, 2010).

3.6. Participatory methods

What are participatory methods?

Qualitative studies use participatory approaches and other qualitative tools to assess the impact, or perceived impact, of weather and climate information on decision making and livelihoods (Tall et al., 2018). There is no single methodological approach to assess WCS using participatory approaches; the common theme within qualitative studies of weather and climate services is the involvement of the user/decision-maker in the evaluation process (Bruno Soares et al., 2018). Qualitative studies can also be used to understand access and usability of WCS from the point of view of the end user. Studies around access and usability provide an important insight into maximising the benefits of WCS (e.g. by removing barriers to use), but do not provide evidence of SEBs in themselves. They are nevertheless an important part of evaluation and often take place together in a single study. Calling on work by Tall et al, (2018), methods may include: **hypothetical decision activities** as used by Roudier et al. (2014) to understand how weather forecasts could influence planting or other farming practices in; **household surveys** as used by Mudombi and Nhamo (2014) who found that many farmers in Zimbabwe considered rainfall predictions and drought warnings to be an important part of their decision-making, although they were not always able to respond to warnings; **semi-structured interviews** as used by Siregar and Crane (2011) who spoke to farmers at a Farmer Field School in Indonesia and found a lack of understanding of climate information was not a limiting factor, rather social and technical barriers limited the ability use seasonal forecasts; and, **mixed methods (surveys and interviews)** as used by Venkatasubramanian et al. (2014) who concluded that when women were fully engaged in India's Agro-Meteorological Advisory Service (AAS) the benefits of the service were maximized.

Qualitative research can reveal important and detailed insights about the impact of a weather or climate service, but it has limitations. One of these limitations is the issue of generalisability. To what extent do the findings apply to other communities or different contexts? (Leung, 2015). However, meta-ethnography provides one way of overcoming this. Meta-ethnography is a method for reviewing and synthesising the findings of qualitative research (Noblit and Hare, 1988). A key principle of meta-ethnography is that insights that were not evident in a single case study are revealed through a process of synthesising multiple case studies.

Is a participatory approach the correct method for my study?

Advantages of participatory approaches?

- Produces a deep qualitative understanding of the impact of weather and climate services on end users
- Can be conducted ex-post or ex-ante
- Gives detailed insight into a specific study site

Limitations of participatory approaches:

- Can be time consuming
- Requires lots of data collection
- Relies on the cooperation of end users
- May not be generalizable

Case study of the participatory approach

Nidumolu et al. (2020) used a mixed methods approach to evaluate the benefits of community-led climate information centres (CLICs) in India. CLICs provide village level meteorological data to farmers, as well as advice on agricultural management in response to weather forecasts. As part of the study, a weather station was established in eight case study villages in Telangana state in southern India. At the same time, locally based NGOs formed and supported 'farmer climate clubs'. Farmer clubs worked with the NGO to produce locally relevant advisories that were displayed in a central location within the village The CLIC centre was also home to a CLIC facilitator who was able to guide farmers through a software interface designed to answer questions related to their farming. The interface guides farmers to relevant videos, visuals and other content.

During the evaluation, a research team surveyed 330 farmers across the eight villages using a structured questionnaire. Additionally, two focus group discussions took place in each village. Focus groups were split by gender with 15 farmers participating in each. Finally, one to one semi-structured interviews with four farmers in each village (a total of 32 across the eight villages) were conducted. Data collection focused on the general perception about CLICs, as well as self-rating in terms of benefits.

The research team showed that around 80% of the surveyed farmers had visited the CLICs during the assessment, but fewer socially disadvantaged farmers, including women farmers had visited. Farmers reported that weather and pest related information was the most useful. In terms of tangible benefits, the average cost savings reported was US$ 4 – 64 per farmer hectare/year.

4. The future of SEB evaluations for NMHS

SEB studies of WCS are not common within NMHSs but this may soon change (Allis et al., 2019). In their 2017 midterm report, the Global Framework for Climate Services (GFCS), a major influence on the practice of, and discourse on, climate services (Gerlak and Greene, 2019) called for a greater focus on evaluation within NMHSs. The report noted that many of the successes attributed to this type of services are going unnoticed because there is no formal recording process or metrics to track their progress and advances made in their implementation and use. As interest in WCS continues to grow (Vaughan and Dessai, 2014) understanding their added value and benefits become all the more important.

The WMO (2015) state that in order to consistently demonstrate these benefits, there must be a wide pool of people across disciplines available to provide technical support and training to NMHs. Providing training on the methods outlined in this report allows NHMSs to take control of the evaluation process and creates an opportunity for ensuring that evaluations become part of project design in WCS. An effort across all NHMSs to evaluate current and future WCS will generate more case studies and provide an evidence base of what works and in what circumstances.

References

ADAMOWICZ, W., BOXALL, P., WILLIAMS, M. & LOUVIERE, J. 1998. Stated preference approaches for measuring passive use values: choice experiments and contingent valuation. *American Journal of Agricultural Economics,* 80**,** 64-75.

AHSAN, M. N., KHATUN, A., ISLAM, M. S., VINK, K., OOHARA, M. & FAKHRUDDIN, B. S. 2020. Preferences for improved early warning services among coastal communities at risk in cyclone prone south-west region of Bangladesh. *Progress in Disaster Science***,** 100065.

AJZEN, I. 2011. The theory of planned behaviour: reactions and reflections. Taylor & Francis.

ALLIS, E., HEWITT, C., NDIAYE, O., HAMA, A., FISCHER, A. M., BUCHER, A., SHIMPO, A., PULWARTY, R., MASON, S., BRUNET, M. & TAPIA, B. 2019. The Future of Climate Services. *In:* WMO (ed.). Online at: https://public.wmo.int/en/resources/bulletin/future-of-climate-services.

ALVAREZ-FARIZO, B. 1999. Estimating the benefits of agri-environmental policy: econometric issues in open-ended contingent valuation studies. *Journal of Environmental Planning and Management,* 42**,** 23-43.

AMEGNAGLO, C. J., ANAMAN, K. A., MENSAH-BONSU, A., ONUMAH, E. E. & GERO, F. A. 2017. Contingent valuation study of the benefits of seasonal climate forecasts for maize farmers in the Republic of Benin, West Africa. *Climate Services,* 6**,** 1-11.

AMOAH, A., FERRINI, S. & SCHAAFSMA, M. 2019. Electricity outages in Ghana: Are contingent valuation estimates valid? *Energy Policy,* 135**,** 110996.

ANAMAN, K., LELLYETT, S. & AVSAR, S. G. 1997. Economic analysis of the effect of aviation weather forecasts on fuel expenditures of Qantas Airways Limited. Online at: http://vuir.vu.edu.au/25707/1/TECHNICALREPORT81_compressed.pdf.

ANAMAN, K. A. & LELLYETT, S. C. 1996. Assessment of the benefits of an enhanced weather information service for the cotton industry in Australia. *Meteorological Applications,* 3**,** 127-135.

ANDERSSON, J. E. 2007. The recreational cost of coral bleaching—a stated and revealed preference study of international tourists. *Ecological Economics,* 62**,** 704-715.

BARBIER, E. B., BAUMGÄRTNER, S., CHOPRA, K., COSTELLO, C., DURAIAPPAH, A., HASSAN, R., KINZIG, A., LEHMAN, M., PASCUAL, U. & POLASKY, S. 2009. *The valuation of ecosystem services*.

BERROCAL, V. J., RAFTERY, A. E., GNEITING, T. & STEED, R. C. 2010. Probabilistic weather forecasting for winter road maintenance. *Journal of the American Statistical Association,* 105**,** 522-537.

BLALOCK, J. 2017. *Causal models in the social sciences*, Routledge.

BRUNO SOARES, M. & BUONTEMPO, C. 2019. Challenges to the sustainability of climate services in Europe. *Wiley Interdisciplinary Reviews: Climate Change,* 10**,** e587.

BRUNO SOARES, M., DALY, M. & DESSAI, S. 2018. Assessing the value of seasonal climate forecasts for decision-making. *Wiley Interdisciplinary Reviews: Climate Change,* 9**,** e523.

BURGESS, R., DESCHENES, O., DONALDSON, D. & GREENSTONE, M. 2014. The unequal effects of weather and climate change: Evidence from mortality in India. *Cambridge, United States: Massachusetts Institute of Technology, Department of Economics. Manuscript.*

CAPLIN, A. & DEAN, M. 2011. Search, choice, and revealed preference. *Theoretical Economics,* 6**,** 19-48.

CARSON, R. T., FLORES, N. E. & MEADE, N. F. 2001. Contingent Valuation: Controversies and Evidence. *Environmental and Resource Economics,* 19**,** 173-210.

CARSON, R. T. & GROVES, T. 2007. Incentive and informational properties of preference questions. *Environmental and Resource Economics,* 37**,** 181-210.

CHIABAI, A., SPADARO, J. V. & NEUMANN, M. B. 2018. Valuing deaths or years of life lost? Economic benefits of avoided mortality from early heat warning systems. *Mitigation and Adaptation Strategies for Global Change,* 23**,** 1159-1176.

CLEMENTS, J., RAY, A. & ANDERSON, G. 2013. The Value of Climate Services Across Economic and Public Sectors. *Report to the United States Agency for International Development (USAID).*

Online at: https://www.climate-services.org/wp-content/uploads/2015/09/CCRD-Climate-Services-Value-Report_FINAL.pdf.
COSTANZA, R., D'ARGE, R., DE GROOT, R., FARBER, S., GRASSO, M., HANNON, B., LIMBURG, K., NAEEM, S., O'NEILL, R. V. & PARUELO, J. 1997. The value of the world's ecosystem services and natural capital. *Nature,* 387**,** 253-260.
COSTELLO, C. J., ADAMS, R. M. & POLASKY, S. 1998. The value of El Niño forecasts in the management of salmon: a stochastic dynamic assessment. *American Journal of Agricultural Economics,* 80**,** 765-777.
EBI, K. L., TEISBERG, T. J., KALKSTEIN, L. S., ROBINSON, L. & WEIHER, R. F. 2004. Heat watch/warning systems save lives: estimated costs and benefits for Philadelphia 1995–98. *Bulletin of the American Meteorological Society,* 85**,** 1067-1074.
EPA, U. S. 2014. Guidelines for preparing economic analysis. Online at: https://www.epa.gov/sites/production/files/2017-08/documents/ee-0568-50.pdf.
FAKHRUDDIN, B. S. & SCHICK, L. 2019. Benefits of economic assessment of cyclone early warning systems-A case study on Cyclone Evan in Samoa. *Progress in Disaster Science,* 2**,** 100034.
FREI, T., VON GRÜNIGEN, S. & WILLEMSE, S. 2014. Economic benefit of meteorology in the Swiss road transportation sector. *Meteorological Applications,* 21**,** 294-300.
GERLAK, A. K. & GREENE, C. 2019. Interrogating vulnerability in the Global Framework for Climate Services. *Climatic Change,* 157**,** 99-114.
HALLEGATTE, S. 2012. A cost effective solution to reduce disaster losses in developing countries: hydro-meteorological services, early warning, and evacuation, Policy Research Working Paper 6058. The World Bank, Online at: http://documents.worldbank.org/curated/en/190261468181486694/A-cost-effective-solution-to-reduce-disaster-losses-in-developing-countries-hydro-meteorological-services-early-warning-and-evacuation.
HAUSMAN, J. A. 2012. *Contingent valuation: A critical assessment*, Elsevier.
HEWITT, C., MASON, S. & WALLAND, D. 2012. The global framework for climate services. *Nature Climate Change,* 2**,** 831.
KUBISZEWSKI, I., COSTANZA, R., DORJI, L., THOENNES, P. & TSHERING, K. 2013. An initial estimate of the value of ecosystem services in Bhutan. *Ecosystem Services,* 3**,** e11-e21.
LAZO, J. K. 2015. Survey of Mozambique public on weather, water, and climate information. *National Center for Atmospheric Research Technical Notes NCAR/TN-521+ STR. Colorado*.
LAZO, J. K., RAUCHER, R. S., TEISBERG, T. J., WAGNER, C. J. & WEIHER, R. F. 2008. Primer on economics for national meteorological and hydrological services. Online at: https://www.wmo.int/pages/prog/amp/pwsp/documents/Primer_on_Economics_for_NMHS_2008_01.pdf. .
LECHTHALER, F. & VINOGRADOVA, A. 2017. The climate challenge for agriculture and the value of climate services: Application to coffee-farming in Peru. *European Economic Review,* 99**,** 5-30.
LEUNG, L. 2015. Validity, reliability, and generalizability in qualitative research. *Journal of Family Medicine and Primary care,* 4**,** 324.
LIAO, S.-Y., CHEN, C.-C. & HSU, S.-H. 2010. Estimating the value of El Nino southern oscillation information in a regional water market with implications for water management. *Journal of Hydrology,* 394**,** 347-356.
LOOMIS, J., KENT, P., STRANGE, L., FAUSCH, K. & COVICH, A. 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. *Ecological Economics,* 33**,** 103-117.
LUMBROSO, D., SUCKALL, N., NICHOLLS, R. & WHITE, K. 2017. Enhancing resilience to coastal flooding from severe storms in the USA: international lessons. *Natural Hazards and Earth System Sciences,* 17**,** 1357-1373.

MEZA, F. J. & WILKS, D. S. 2004. Use of seasonal forecasts of sea surface temperature anomalies for potato fertilization management. Theoretical study considering EPIC model results at Valdivia, Chile. *Agricultural Systems,* 82**,** 161-180.
MJELDE, J. W., PENSON JR, J. B. & NIXON, C. J. 2000. Dynamic aspects of the impact of the use of perfect climate forecasts in the Corn Belt region. *Journal of Applied Meteorology,* 39**,** 67-79.
MUDOMBI, S. & NHAMO, G. 2014. Access to weather forecasting and early warning information by communal farmers in Seke and Murewa districts, Zimbabwe. *Journal of Human Ecology,* 48**,** 357-366.
MURPHY, J. J., ALLEN, P. G., STEVENS, T. H. & WEATHERHEAD, D. 2005. A meta-analysis of hypothetical bias in stated preference valuation. *Environmental and Resource Economics,* 30**,** 313-325.
NEPAL, M., BERRENS, R. & BOHARAC, A. 2009. Assessing Perceived Consequentiality: Evidence from a Contingent Valuation Survey on Global Climate Change. *Forthcoming in International Journal of Ecological Economics and Statistics*

14, P09, Spring 2009**,** 14-29.
NIDUMOLU, U., ADUSUMILLI, R., TALLAPRAGADA, C., ROTH, C., HOCHMAN, Z., SREENIVAS, G., RAJI REDDY, D. & RATNA REDDY, V. 2020. Enhancing adaptive capacity to manage climate risk in agriculture through community-led climate information centres. *Climate and Development***,** 1-12.
NOBLIT, G. W. & HARE, R. D. 1988. *Meta-ethnography: Synthesizing qualitative studies*, Sage.
PAUL, B. K. & DUTT, S. 2010. Hazard warnings and responses to evacuation orders: the case of Bangladesh's cyclone Sidr. *Geographical Review,* 100**,** 336-355.
RASUL, G. 2009. Ecosystem services and agricultural land-use practices: a case study of the Chittagong Hill Tracts of Bangladesh. *Sustainability: Science, Practice and Policy,* 5**,** 15-27.
ROGERS, D. P. & TSIRKUNOV, V. V. 2013. *Weather and climate resilience: Effective preparedness through national meteorological and hydrological services*, The World Bank, Online at: http://dx.doi.org/10.1596/978-1-4648-0026-9.
ROSENBERGER, R. S. 2015. Benefit transfer validity and reliability. *Benefit Transfer of Environmental and Resource Values.* Springer.
ROSENBERGER, R. S. & STANLEY, T. D. 2006. Measurement, generalization, and publication: Sources of error in benefit transfers and their management. *Ecological Economics,* 60**,** 372-378.
ROUDIER, P., MULLER, B., D'AQUINO, P., RONCOLI, C., SOUMARÉ, M. A., BATTÉ, L. & SULTAN, B. 2014. The role of climate forecasts in smallholder agriculture: lessons from participatory research in two communities in Senegal. *Climate Risk Management,* 2**,** 42-55.
RUBAS, D. J., HILL, H. S. & MJELDE, J. W. 2006. Economics and climate applications: exploring the frontier. *Climate Research,* 33**,** 43-54.
SCHLÄPFER, F. 2006. Survey protocol and income effects in the contingent valuation of public goods: A meta-analysis. *Ecological Economics,* 57**,** 415-429.
SIREGAR, P. R. & CRANE, T. A. 2011. Climate information and agricultural practice in adaptation to climate variability: the case of climate field schools in Indramayu, Indonesia. *Culture, Agriculture, Food and Environment,* 33**,** 55-69.
STEWART, T. R. 1997. Forecast value: Descriptive decision studies. Cambridge University Press New York.
TALL, A., COULIBALY, J. Y. & DIOP, M. 2018. Do climate services make a difference? A review of evaluation methodologies and practices to assess the value of climate information services for farmers: Implications for Africa. *Climate Services,* 11**,** 1-12.
TALL, A., DAVIS, A. & AGRAWAL, S. 2014. Does climate information matter? A proposed monitoring and evaluation framework for participatory assessment of the impact of climate services for male and female farmers. Online at: https://cgspace.cgiar.org/bitstream/handle/10568/41732/CCAFS%2520WP%252069.pdf?sequence=1.

TEISBERG, T. J. & WEIHER, R. F. 2009. Background paper on the benefits and costs of early warning systems for major natural hazards. *The World Bank, Online at: https://www.gfdrr.org/sites/gfdrr/files/Teisberg_EWS.pdf.*

TOMPKINS, E. L. & EAKIN, H. 2012. Managing private and public adaptation to climate change. *Global Environmental Change,* 22**,** 3-11.

TUNÇEL, T. & HAMMITT, J. K. 2014. A new meta-analysis on the WTP/WTA disparity. *Journal of Environmental Economics and Management,* 68**,** 175-187.

VAUGHAN, C. & DESSAI, S. 2014. Climate services for society: origins, institutional arrangements, and design elements for an evaluation framework. *Wiley Interdisciplinary Reviews: Climate Change,* 5**,** 587-603.

VENKATASUBRAMANIAN, K., TALL, A., HANSEN, J. & AGGARWAL, P. K. 2014. Assessment of India's Integrated Agro-meteorological Advisory Service from a farmer perspective. *CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).* Online at: https://cgspace.cgiar.org/bitstream/handle/10568/43733/CCAFS%20WP%2054.pdf.

WHITEHEAD, J. C., PATTANAYAK, S. K., VAN HOUTVEN, G. L. & GELSO, B. R. 2008. Combining revealed and stated preference data to estimate the nonmarket value of ecological services: an assessment of the state of the science. *Journal of Economic Surveys,* 22**,** 872-908.

WMO 2015. Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services Online at: https://library.wmo.int/doc_num.php?explnum_id=3314.

WMO 2018. Step-by-step Guidelines for Establishing a National Framework for Climate Services. Online at: https://library.wmo.int/index.php?lvl=notice_display&id=20216#.XoMENIjdvIU.

Appendix 1: Overview of evaluation methods (adapted from WMO, 2015)

	Method	Description	Advantages	Disadvantages	Can be used ...	Example
Stated preference	Contingent valuation (CV)	• Survey based elicitation of individuals' preferences and values (e.g. WTP)	• Estimates use and non-use values • Incorporates hypothetical scenarios that closely respond to policy case	• Time intensive and expensive to implement • Challenging to frame survey questions that elicit valid responses • Potential response bias	• For evaluating existing or non-existing WCS • In ex-ante and ex-post evaluations • To analyse a service with a large or small number of users • Across all temporal scales of weather and climate information • For evaluations at various spatial scales (although the higher the level the more difficult it may be to implement the survey	Page 9
Revealed preference	Averting behaviour	• Determines values based on expenditures that would have been made to reduce impacts of weather or climate events but were avoided because of improved met/hydro information.	• Uses observed data to conduct ex-post analysis • Tailored to a specific policy case • Expenditures easy to estimate through surveys	• Values interpreted as lower bound estimates because averting expenditures only capture a portion of an individual's WTP to avoid a particular harm	• For evaluating only existing WCS • In ex-post evaluations • To analyse a service with a large or small number of users • Across all temporal scales of weather and climate information • For evaluations at various spatial scales (although the higher the level the more difficult it may be to implement the survey	Page 11

	Travel cost or expenditure modelling	• Uses observed tourist or recreational trip taking behaviour to determine whether people pay more to visit sites for which forecasts are available. • Can rely on other expenditures or costs incurred to search for or obtain met/hydro information.	• Uses observed data to conduct ex-post analysis • Tailored to a specific policy case	• Measures use value only • Collecting adequate data is often expensive and time intensive	• For evaluating only existing WCS • In ex-post evaluations • To analyse a service with a large or small number of users • Across all temporal scales of weather and climate information	
	Hedonic analysis	• Using observed housing, property or labour market behaviour to infer values for quality changes.	• Uses observed data to conduct ex-post analysis • Tailored to a specific policy case	• Measures use value only • Requires extensive market data • Assumes that market prices capture the good's value	• For evaluating only existing WCS • In ex-post evaluations • To analyse a service with a large or small number of users • Across all temporal scales of weather and climate information	
Economic decision modelling	Decision analysis	• Analyses decisions and resulting values when people have access to NMHS and when they do not. • Typically paired with business or production models.	• Useful to examine decisions or expected outcomes at household or firm level • Can be relatively simple to perform depending on model used	• Can be time and data intensive depending on model used • Requires sector expertise (e.g. transport, agriculture) • Often assumes perfect information as a simplifying measure	• For evaluating hypothetical WCS • In ex-ante evaluations • To analyse a service with a large or small number of users • Across all temporal scales of weather and climate information	Page 13

	Equilibrium modelling	• Examines changes in supply and demand and price effects associated with use of NMHS. • Measures resulting gains/losses for producers and consumers.	• Partial equilibrium modelling useful to examine benefits of NMHS for a specific sector	• Time and data intensive • Can be expensive to implement • Requires significant expertise	• For evaluating hypothetical WCS • In ex-ante evaluations • To analyse a service with a large or small number of users • Across all temporal scales of weather and climate information	
	Econometric modelling	• Examines statistical relationships to determine specific outcomes associated with NMHS. • Regression analysis is the most common form of econometric modelling.	• Uses observed data to conduct ex-post and ex-ante analysis	• Can require significant amounts of data and expertise	• For evaluating hypothetical and existing WCS • In ex-post and ex-ante evaluations • To analyse a service with a large number of users • Across all temporal scales of weather and climate information	
Avoided cost assessment		• Evaluates benefits based on avoided cost of weather and climate events due to better met/hydro information, included avoided assets losses, lives saved and avoided morbidity impacts.	• Can be applied in ex-post and ex-ante analysis • Relativity easy to implement	• Only represents partial value (e.g. it does not consider benefits of NMHS associated with increase productivity and enjoyment)	• For evaluating hypothetical and existing WCS • In ex-post and ex-ante evaluations • To analyse a service with a large or small number of users • Across all temporal scales of weather and climate information	Page 15
Benefit transfer		• Applies results of existing valuation studies and transfers them to a different	• Relatively simple and inexpensive • Accepted as a suitable method for	• Can generate potentially inaccurate and misleading results	• For evaluating hypothetical and existing WCS • In ex-post and ex-ante evaluations	Page 17

		context (for example, a different geographic area or policy context).	estimating order of magnitude values for use and non-use benefits, in ex-post and ex-ante analyses	• Limited number of original studies	• To analyse a service with a large or small number of users • Across all temporal scales of weather and climate information	
Participatory methods		• Produces a deep qualitative understanding of the impact of weather and climate services on end users	• Can be conducted ex-post or ex-ante • Gives detailed insight into a specific study site	• Can be time consuming • Requires lots of data collection • Relies on the cooperation of end users	• For evaluating hypothetical and existing WCS • In ex-post and ex-ante evaluations • To analyse a service with a large or small number of users • Across all temporal scales of weather and climate information	Page 19