CLARA

Climate forecasts enabled knowledge services

Evaluating Climate Services

Experiences from the CLARA project

Jaroslav Mysiak, Elisa Delpiazzo, Francesco Bosello
Euro-Mediterranean Centre on Climate Change (CMCC)

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Euro-Mediterranean Centre on Climate Change

research & innovation - policy & cooperation

- Centre of competence for multidisciplinary research on climate change
- Copernicus Marine Environment Service, Mediterranean Monitoring and Forecasting Centre; Copernicus Seasonal forecast
- Focal point of the Intergovernmental panel on Climate Change (IPCC)
- European Topic Centre on Climate Change impacts, vulnerability and adaptation and on inland, coastal and marine waters of the European Environment Agency
- Coordinating entity for the Italian National Climate Adaptation Strategy and Plan

Outline and some key messages

Keep in mind that

- climate services are a special type of knowledge-intensive (business) services, this is relevant for assessing the benefits they offer,
- evaluation of users' monetary benefits from climate services is important, but so is the understanding of (non-monetary) values and drives for diffusion and adoption of services,
- ways to create value by targeted use of climate information, hand in hand with innovative ways to capture and detain this value characterize climate innovation.

Outline of my talk

- Climate services and climate innovation – what makes the assessment different
- What methods and tools,
- CLARA methods and some examples

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On climate services

Climate innovation and piloted climate services produce action-oriented knowledge that rally transformational change

- spurred by multilateral frameworks such as UN Sustainable Development Agenda, Sendai Framework for Disaster Risk Reduction, and UNFCCC Paris Agreement on Climate Change.

Climate services are knowledge-intensive business services

- advanced technological and professional knowledge; both users and purveyors play a vital role in co-designing and co-producing the service solutions

Instead of a definition

- Historic climate records, catalogues of extreme events, reanalyses, forecasts, projections and indices used in outlooks, early warnings, vulnerability and risk assessments, monitoring and reporting schemes, and financial protection instruments ….
- …. enable higher agricultural productivity, more efficient use and allocation of water, greater financial security and returns on investments, more reliable access to and production of renewable energy, and more effective protection of vulnerable communities and ecosystems.

On climate services (II)

Climate services generate private and collective benefits.

- Private benefits materialise through cost reduction, increased yields and incomes, better-informed planning and protection against unforeseen events, and potential of new entre-preneurial ventures.
- Collective benefits are embedded in greater water, energy and food security; enhanced resilience, adaptive capacity, and innovation-prone policy and business environments..

Collective benefits are sizeable after a critical mass of uptake/use of services was reached.

- Irrigation services for example may lead to greater on-farm water-use efficiency but if water tariffs are low or insensitive to actual water consumption, farmers gain little from a change. Collective benefits from adoption of irrigation services at large scale are sizeable both in terms of higher reliability of water supply as well as the possibility to allocate the conserved water to new users.

On climate services (III)

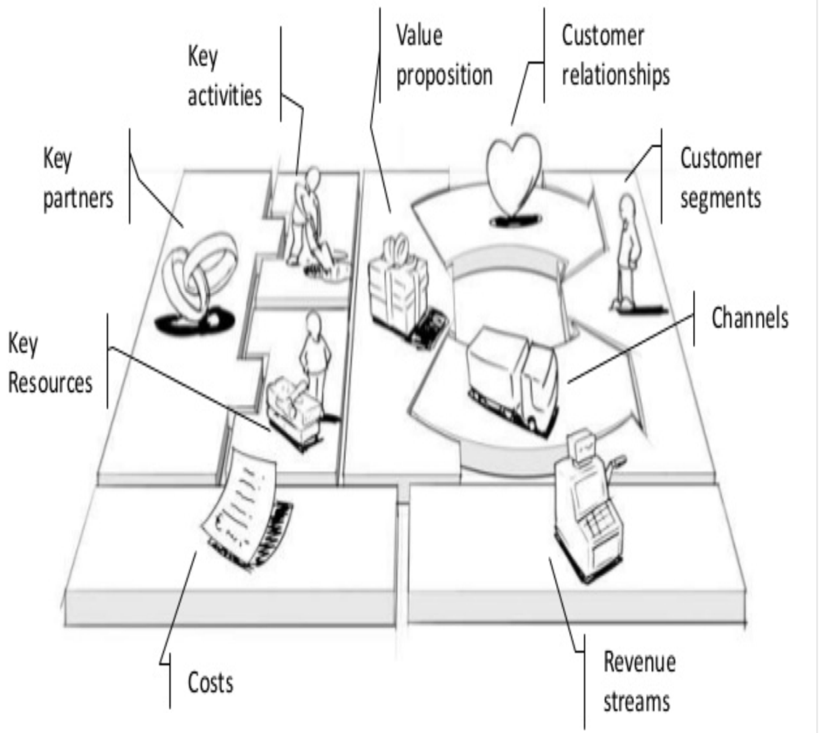
Costs of user-deployed climate services is not limited to the price paid for their provision.

- Users' capacity to assimilate climate knowledge for operational management and strategic choices are associated with substantial costs related to business and operational reorganisation, capacity building and knowledge management, above and beyond the price of climate services.
- Strategic knowledge management positively influences innovation and performance but many organisations are not fully aware of the implycations.
- The initial costs are progressively lowered and outpaced by benefits obtained from custom-built climate service.

Value proposition

Sustainable business innovation has prompted a diversity of mechanisms to capture and detain value generated by climate services.

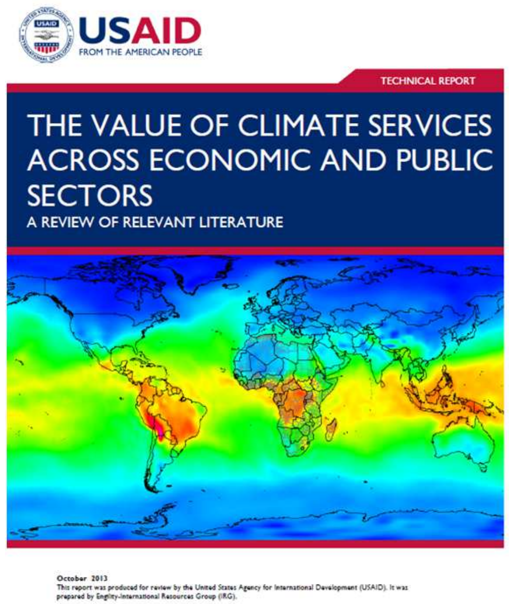
- full potential of business model innovation has yet to be exploited and the market growth will depend on the ability to harness this innovation.
- innovation in business model as a means of creating value is a new field of innovation research and practice. Therein, financial models addressing revenue flows and distribution of economic costs and benefits are fundamental for business viability

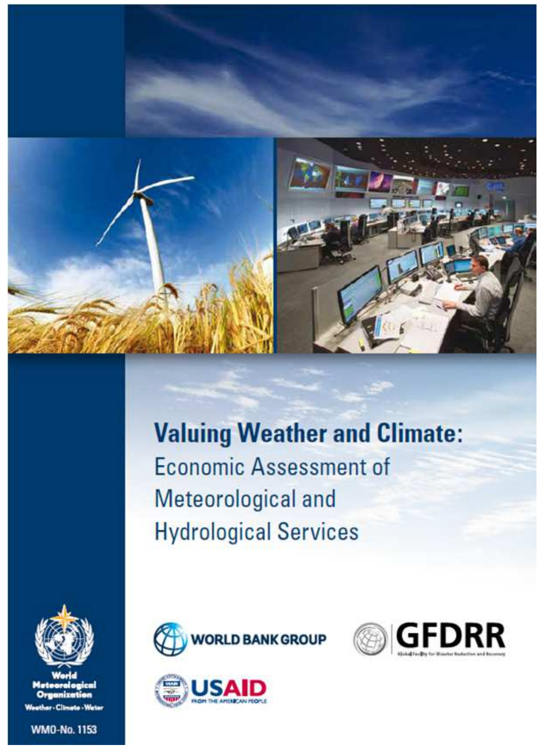


Overview of other studies

Economic Valuation of Climate Services Working Group of the Climate Services Partnership (CSP)

- Set up to demonstrate the benefits of climate services and help providers prioritize opportu-nities for expanding their use.
- 2013: The Value of Climate Services across Economic Boundaries: A Review of Relevant Literature,
- 2015 - Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services





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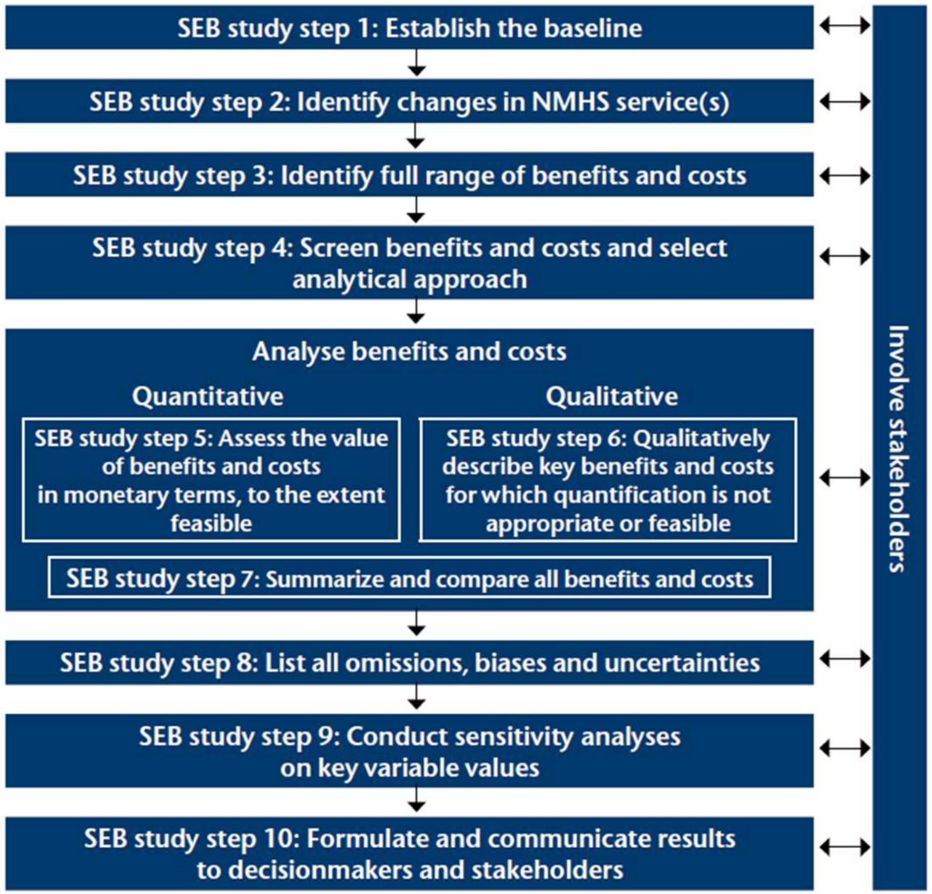
Overview of other studies

Clements et al, 2013: 139 primary studies with agriculture as dominant field – rainfed and irrigated agriculture, to lesser extent water resources management, transportation and tourism, in US and elsewhere.

Tall et al, 2018: overview of quantitative and qualitative methods and review of past studies for agriculture. **Mjelde et al, 1989, WMO 2002** (earlier review of methodological aspects).

Vogel et al, 2014 example of Caribbean Agrometeorological Initiative - provision of climate services including quality, distribution and uptake of information. **Li et al, 2017, Soares et al, 2018,** ….



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Methods

❑ Monetary methods

- informed and evidence-based policy and decision making;
- value proposition for new or enhanced services as a part of business model,
- pricing & charging for services, financial viability,
- Informing investments and justifying public delivery of climate services,

❑ Non-monetary methods

- ability of users and organisations to access, understand/assimilate, and apply operational services, including users' satisfaction and usability,
- explain or evaluate assumptions related to (intended or actual) human behaviour,
- factors driving innovation, technology adoption and diffusion, and studies related to sustainable business models.

➢ important for understanding decision contexts for which service is provided and employed.

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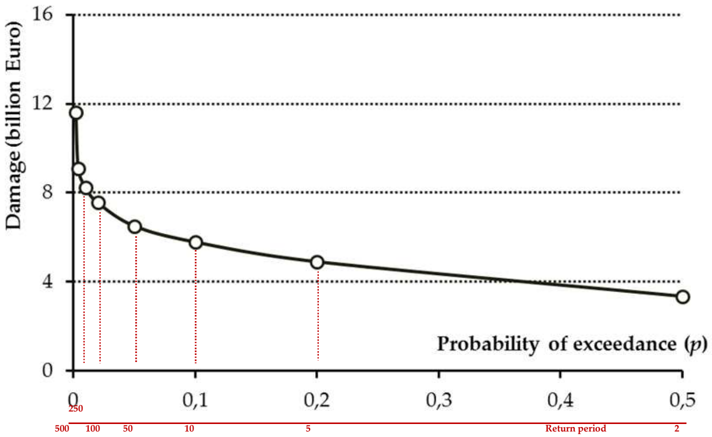
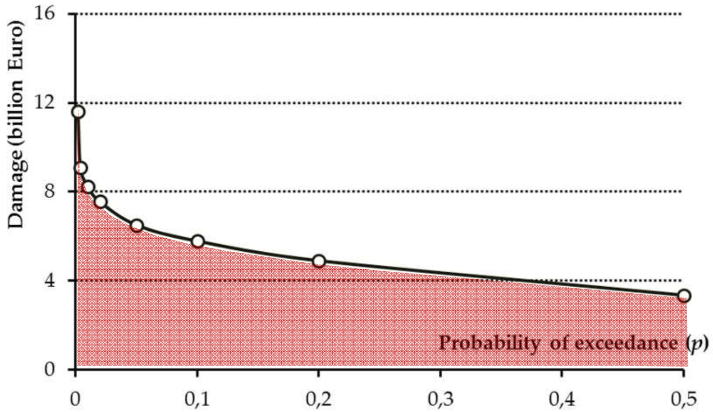
Methods (II)

- **Econometric models** explore the effects of independent variables (e.g. yield, losses) on a series of dependent variables (i.e. employment of climate services). E.g.: Anaman et al. (2000) analyzed the effect of weather forecasts on fuel expenditure of Qantas Airways.
- **Avoided costs/damages** approaches estimate the costs that would have been incurred in the absence of a particular climate service. E.g. Frei et al. (2014) found that the use of meteorological services by the transportation sector in Switzerland would result in US$ 56.1 million to US$ 60.1 million in avoided governmental spending.
- **Decision theory.** It describes how the decisions process is influenced by “new” information and how the outcomes (payoffs) would change accordingly. Ex. Meza and Wilks (2004) estimated the value of optimal sea-surface temperature anomaly forecasts for fertilizer management in Chile.
- **Economic modeling, partial and general equilibrium models**. Improved description of the economic context, that in the case of general equilibrium models accounts for all the feedback across sectors and countries.

Excurse





- Loss exceedance probability (EP) is probability of exceeding given damage/loss threshold in one year. E.g. loss 8 billion represents the 99 percentile of the annual damage/loss distribution. The probability of exceeding 8 billion in one year is 1%.
- Expected annual damage (EAD) and loss (EAL) is a mean value of a damage/loss exceedance probability (EP) distribution; the expected loss per year.

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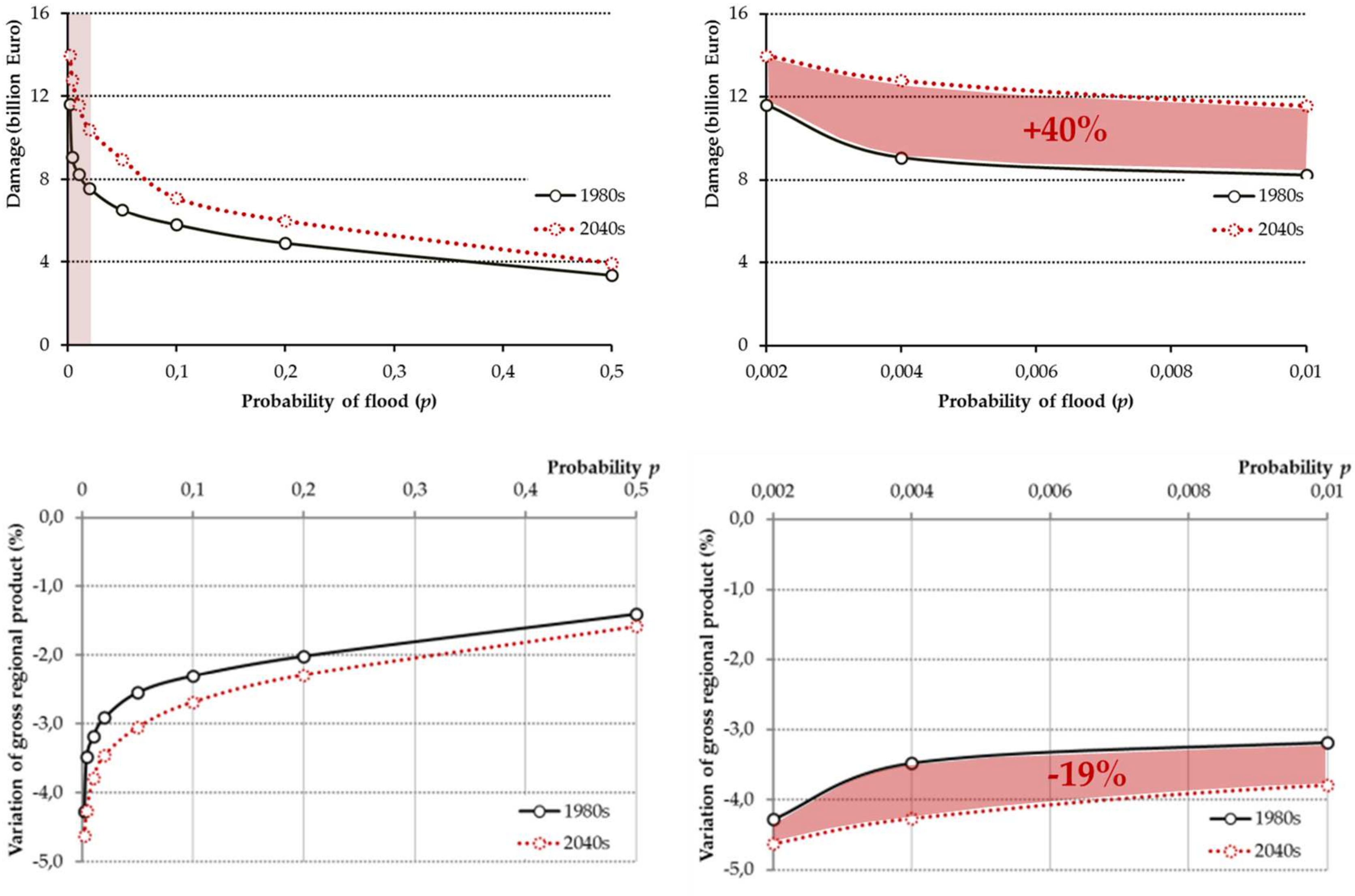

Damage (billion Euro)
Probability of flood (p)
1980s
2040s
+40%
Variation of gross regional product (%)
Probability p
-19%

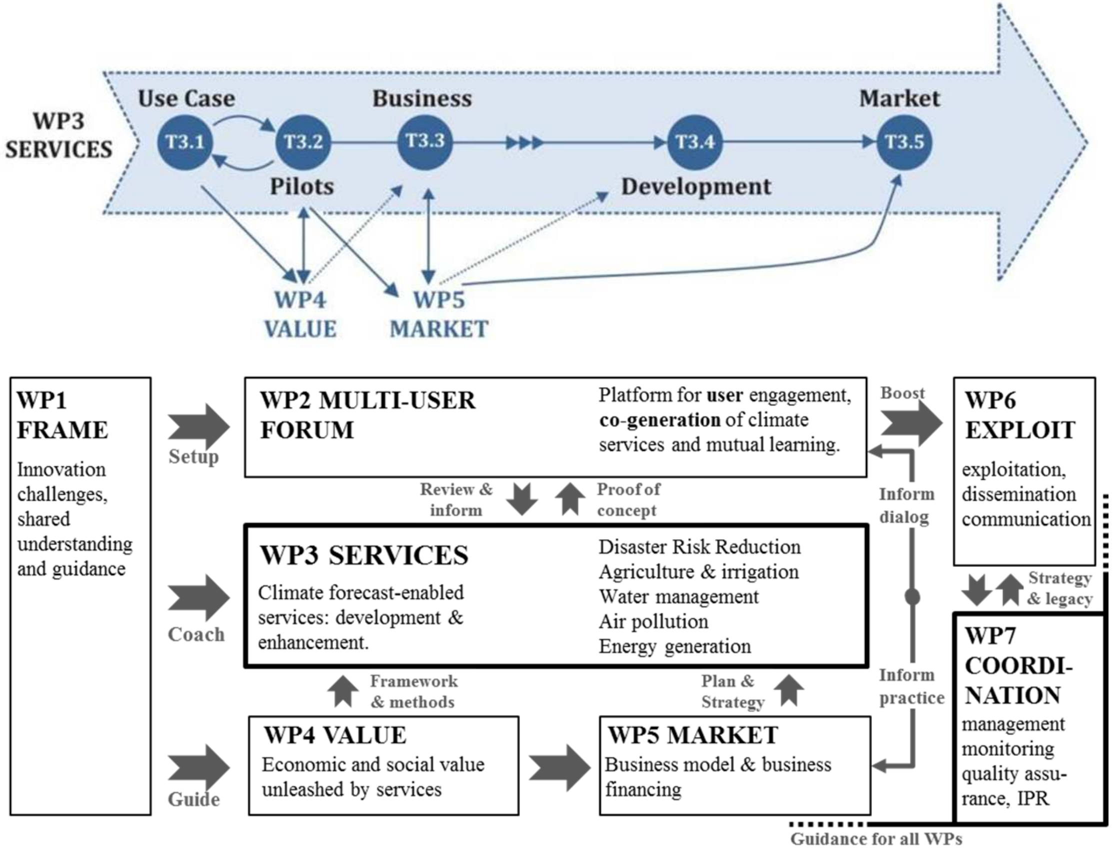
Methods (III)

- **Non-market valuation** techniques have also been used to assign monetary values to climate services, including revealed-preference and stated-preference methods when market evaluation are missing.
- **Benefits transfer**. It is used when no information on a specific location, area, context are available. It applies results of existing valuation studies and transfers them to the new context (e.g. a different geographic area or policy situation) through a process of "rescaling".

CLARA

Climate forecasts enabled knowledge services

- builds upon the operational climate forecasts (seasonal to decadal) and projections of the Copernicus Climate Change Services,
- closely engages some of the new Sectoral Information Systems (SIS),
- includes experienced purveyors (small-medium sized enterprises, SMEs) and public agencies (PAs) with good record in innovation and climate service provision.



CLARA – 14 services in 5 GFCS priority areas

	Product Description	Clara team	User
1	*Economic assessment of flood risk, risk financing*: Based on the projected seasonal and decadal rainfalls (Copernicus C3S) and estimated flood volumes (Copernicus C3S SWICCA models including E-HYPE, VIC and/or LISFLOOD, GLOFRIS and other users' applied models), the CLARA service will estimate the expected material flood damage and the economic losses in terms of gross regional product (GRP), using the CMCC's general equilibrium model (ICES).	CMCC, SMHI ARPAE, RER ISPRA	- Po River Basin Authority, - Italian association of insurers (ANIA), - Italian Civil Protection Department, - Land reclamation boards in Emilia Romagna, - Prime Minister Office's Coordination Unit on flood risk
2	*Water Resource Management Model*: Building upon the projected rainfalls (Copernicus C3S) and runoffs (C3S SWICCA), the CLARA service will estimate the daily average stream flow by using the DEWSPo modelling framework. The service will capture the groundwater (GW)-surface water (SW) interactions.	ARPAE, GECOS, SMHI, RER, ISPRA	- Po River Basin Authority, - Italian Civil Protection Department, - Land reclamation and water boards in Emilia Romagna and elsewhere in Italy
3	*Water Supply Forecasts and Projections.* Building upon CLIM4ENERGY and SWICCA seasonal hydrological forecasts and projections, this service will tailor information about groundwater levels, river flow, lake levels and water temperature for local use by water supply companies.	SMHI, CMCC	- Region Gotland (SE) - Water supply companies
4	*Multi-objective Reservoir Operation Assessment Tool* (ROAT) will provide operational assessment of multi-objective reservoirs (flood control, urban-agriculture-industry water supply, hydropower) based on seasonal and longer-term river-flow forecasts and the environmental flow regime requirements.	UCO, CMCC, SMHI	- South Andalusian River Basin Authority - River Basin Authorities; - Energy market operators; - Farmers' associations;
5	*Water requirements for irrigation* (WRI). Building upon the Arpae's operative agro-climatic services, and the C3S climate forecasts, the service will provide localized advice (e.g. irrigation deficit) on smartphone.	ARPAE, CMCC, SHMI	- Land reclamation and water boards in RER - Farmers and Farmers' Associations,
6	*Soil Water Budget usable Predictor* (SWBP) will be a web mapping application providing high-resolution, spatially distributed agro-meteorological indices such as water budget variables (hydro-climatic balance BIC, Soil Water Content SWC, evapotranspiration, etc).	GECOS, CMCC, SHMI, ARPAE	- Land reclamation and water board of Romagna Occidentale, - Farmers associations, river basin authorities, agricultural regional agencies
7	*Small Hydropower Atlas* (SHPA) supports hydropower suitability and production assessment. Using newly available C3S data, it will be enhanced to include seasonal forecasts of hydroelectricity production. The new service will include a wizard to enable an application at site specific scale, for which user input data and other site specific data is available.	GECOS, CMCC, SHMI, ARPAE	- Nomar Enterprise - Hydropower energy producers, - Regional and river basin authorities issuing HE permits and conducting EIAs
8	*Small HydroPower Assessment Tool* (SHAT) provides river flow predictions in snow dominated areas, considering the environmental flow requirements that limit the water use for hydroelectricity production. It also serves for local environmental impact assessment and support for operational decision-	UCO, SHMI	- Endesa Generación - Energy market operators, - river basin authorities,
9	<u>*Twh Prediction*</u> - a service to predict potential hydro-energy availability in Twh for all time-scales (including seasonal forecasts and future climate projections) will be developed for Scandinavia. The service is intended to optimise buying and selling of energy based on predictions of future availability.	SMHI, CMCC	- Eon - Energy market companies, hydropower production companies
10	*Solar Energy Assessment and Planning Tool* (SEAP) - a service to provide spatial and operational assessment of solar energy systems (SES) based on the prediction of climate variables on different time scales: monthly, seasonal and annual	UCO, CMCC	- Energy market companies; - Solar energy systems technological companies
11	*AirvCloud*: Building upon existing services offering urban climate information of 1x1 km² spatial resolution and a temporal resolution of one hour, CLARA extend this information with an in-cloud air quality modelling tool for high resolution assessments on the local and micro-scale/street level, using C3S Urban SIS data as input and boundary conditions.	SMHI, APERT, ARPAE, DCMR	- Rotterdam municipality/Southern Holland - Consultants and public agencies working in urban infrastructure development
12	CTR-QA will evaluate the feasibility of a new improved air quality scenario analysis service at regional/local spatial scale. The improved service will simulate the air quality in future climate scenarios by running existing numerical models using meteorological input data coming from climate models from SMHI (HARMONIE-ALARO) and boundary conditions from MATCH CTM model. The results of the air quality scenario analysis will be made available by the open data platform (http://dati.arpa.emr.it/.	ARPAE, SMHI, RER, ISPRA	- Northern Italy/Emilia-Romagna region - Public bodies and consultants in air quality management
13	*Posts processed decadal projections* (PPDP). Building on the existing post-processing methodologies and data products based on climate projections, the service will be extended to cover decadal projections.	TCDF	- Acclimatise Group Ltd UK - Climate change adaptation practitioners
14	CLIME- a tailored tool to analyse for observed and simulated climate data. Building upon award winning tool making it possible to analyse ensembles of multi-model climate simulations.	CMCC	- Regional administrations preparing the regional climate adaptation plans

Legend

Disaster risk reduction	Water management	Agriculture	Renewable energy	Air quality and health	Horizontal services

CLARA method

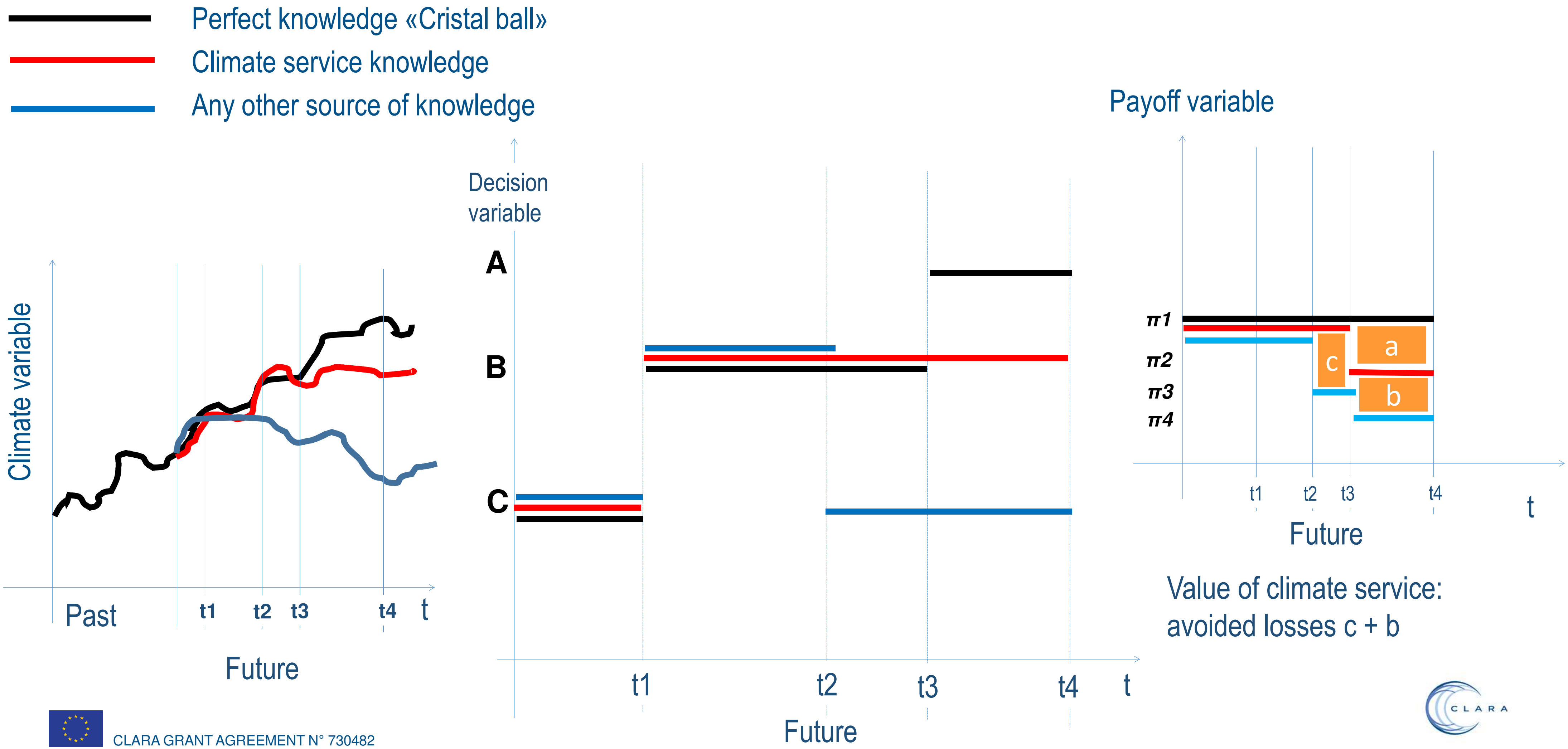
Background

- based on decision theory and 'value of information',
- estimated value is subjective, related to a user – his/her decision/action space and counterfactual information used,
- does not reflect the costs of service assimilation and organisational adaptation; hence reflect the max benefit obtained in the specific situation,
- no spin-off effects on behaviour of other agents is considered,

CS **Value** for a user =

difference of monetized outcome (payoffs) of a decision (path) made **with** and **without** the knowledge obtained form the climate service in question.

expected outcome from an service-assisted decision compared to the expected outcome of the decision without the service


Perfect knowledge «Cristal ball»
Climate service knowledge
Any other source of knowledge
Climate variable
Past
t1
t2
t3
t4
t
Future
Decision variable
A
B
C
t1
t2
t3
t4
t
Future
Payoff variable
π1
π2
π3
π4
a
b
c
t1
t2
t3
t4
t
Future
Value of climate service:
avoided losses c + b

Time (year, month day…)	Prediction of a given climate variable by climate service	Prediction ….. according to an alternative source	Effective realizations …. future-observed value
1			
2			
3			
4			
5			
…			
…			
n			
…			
…			
N			

- Users' decision path based on information received
- Payoffs
  (those related to when the information pinpoints «a» and user acts accordingly and «a» actually occurs, but also to when the information pinpoints «a» and user acts accordingly but «b» occurs)

SHYMAT service evaluation

Objective of the service

Management of small hydropower plants in which operation feasibility is subjected to the run-off-river flow depending on a high variability in precipitation and snow cover.

Actions

Set turbine level according to next month river flow → River flow level ➔ directly related to the amount of energy that can be produced

Payoff

Score ranging from 0 to 10 based upon the amount of energy effectively produced

«States of the world»: **4** different **states** according to the water flow level: (1) U (flow above 1.5 m^3/s), (2) M (flow between 1-1.5 m^3/s), L (flow between 0.3-1 m^3/s), D (flow below 0.3 m^3/s)

Evaluation: compare the payoff (amount of energy) that could have been produced using as a predictor of river flow level in the period 2010-2014 the historical monthly realizations in hydraulic years 2000-2010;against what could have been produced knowing exactly what occurred.

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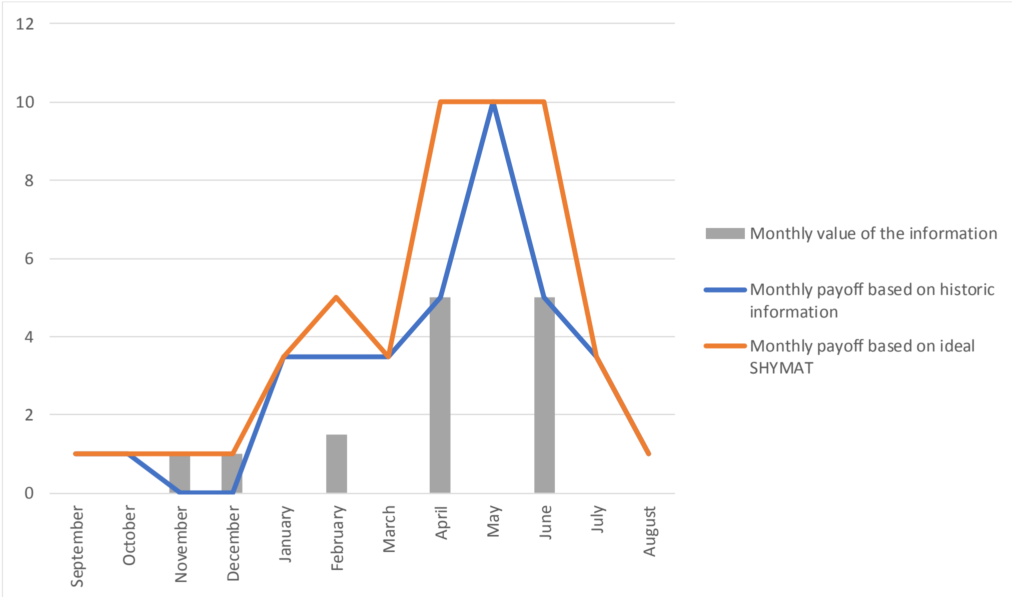
SHYMAT service evaluation (1 year example)

Month	Forecasts based on historic experience	Effective realization based on ideal SHYMAT
September	D	D
October	D	D
November	D	D
December	L	D
January	D	D
February	L	M
March	D	D
April	M	U
May	D	D
June	M	U
July	D	D
August	D	D

Time series of monthly realizations in the hydraulic year 2010-2011



Monthly SHYMAT value in the hydraulic year 2010-2011

Monthly payoffs	U	M	L	D
"U"	10	5	3.5	1
"M"	0	5	3.5	1
"L"	0	0	3.5	1
"D"	0	0	0	1

Monthly payoffs according to prediction and action

Outcomes:

Information value is the vertical difference between blue and orange lines

Total gain: 13.56; monthly average gain: 1.13

SHYMAT service evaluation (4 year example)

Month	Forecasts based on historic experience	Effective realization in 2010-2014
Year 2010-11		
September	D	D
October	D	D
November	D	D
December	D	D
January	L	D
February	L	D
March	L	D
April	L	L
May	M	M
June	M	L
July	L	D
August	D	D
Year 2011-12		
September	D	D
October	D	D
November	D	D
December	D	D
January	L	D
February	L	D
March	L	L
April	M	L
May	M	M
June	M	L
July	L	D
August	D	D

Month	Forecasts based on historic experience	Effective realization in 2010-2014
Year 2012-13		
September	D	D
October	D	D
November	D	D
December	D	L
January	L	L
February	L	L
March	L	M
April	M	U
May	M	L
June	M	D
July	L	D
August	D	D
Year 2013-14		
September	D	D
October	D	D
November	D	D
December	D	D
January	L	D
February	L	D
March	L	M
April	M	U
May	U	U
June	M	U
July	L	M
August	D	D

Time series of monthly realizations in the hydraulic years 2010-2014

Monthly payoffs	U	M	L	D
"U"	10	5	3.5	1
"M"	0	5	3.5	1
"L"	0	0	3.5	1
"D"	0	0	0	1

Monthly payoffs according to prediction and action

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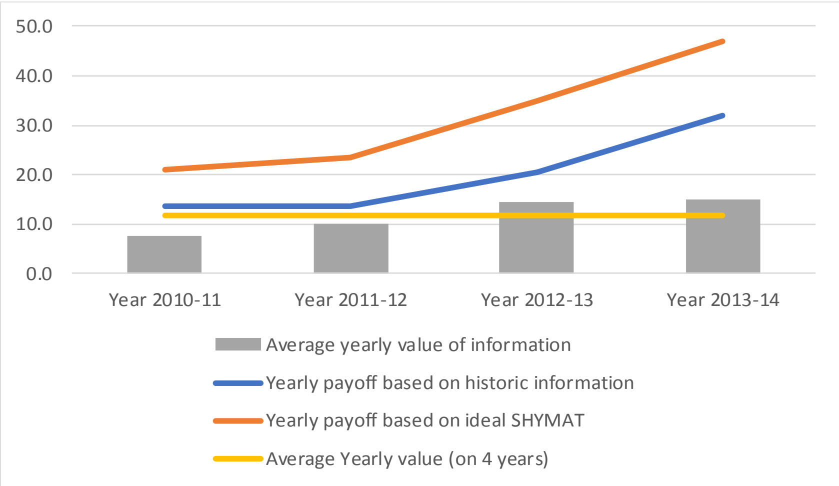
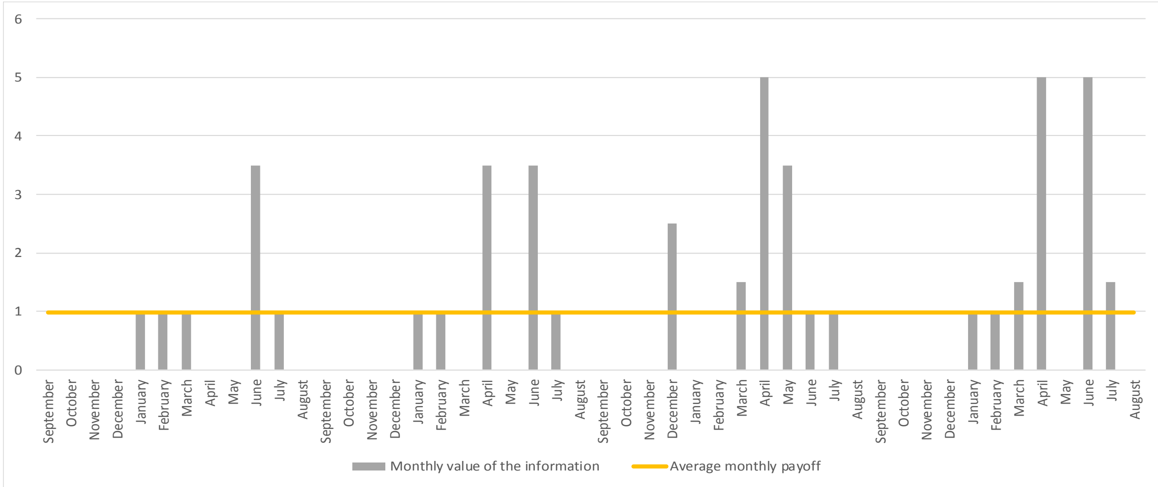
CLARA

SHYMAT service evaluation (4 year example)



Yearly SHYMAT value and payoffs for the hydraulic years 2010-2014



Seasonal SHYMAT value for the hydraulic years 2010-2014

Results:

Using hystorical experience as forecasting method will produce on a yearly basis a payoff that is 32% to 43% lower than the payoff a 100% skill SHYMAT service would produce (4-year average 37%)

Comments:

In our controlled situation («we know the future») we could also see when the service is «most useful» or produces the most valuable information (always wrt the alternative): the highest values are in spring- early summer seasons; while they ar lower in fall/winter

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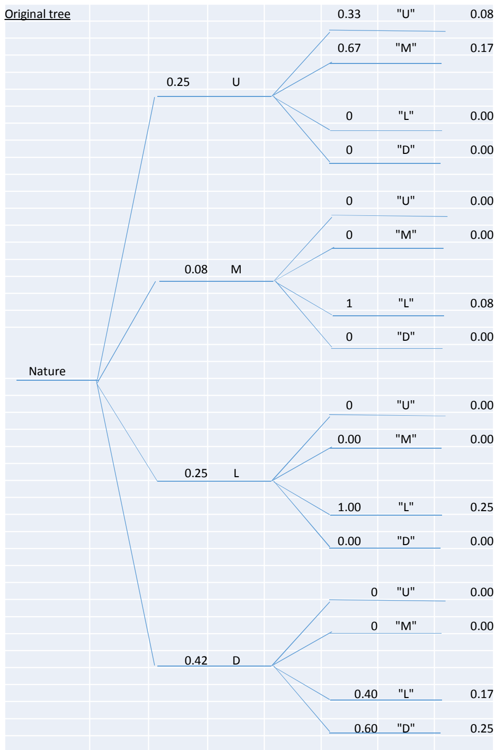
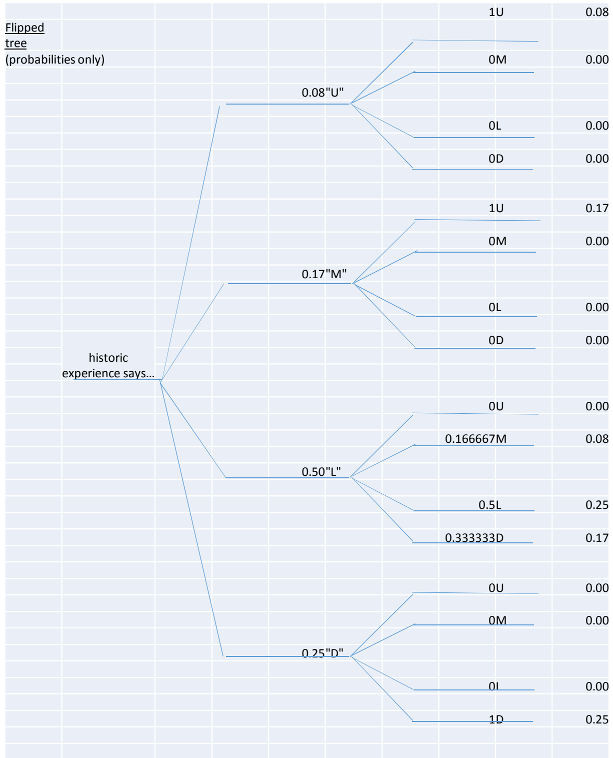
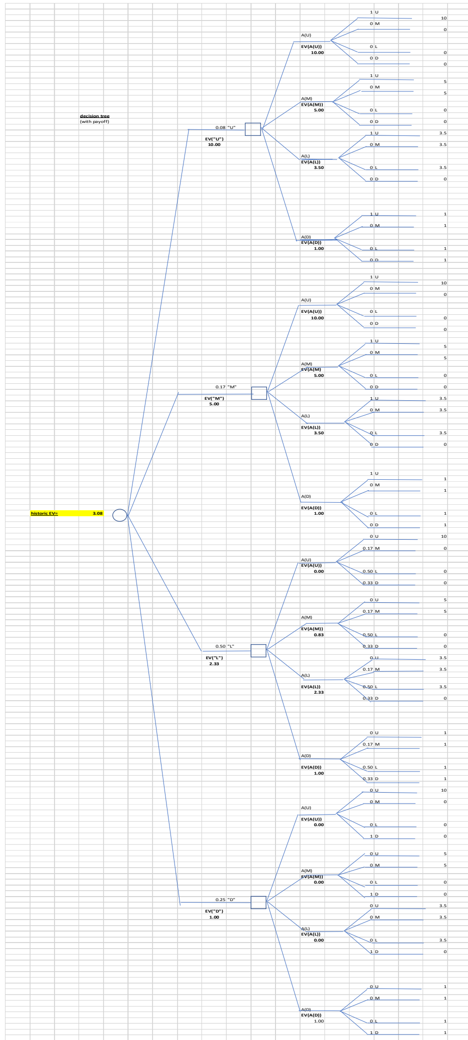
SHYMAT service: theoretical methodology



Original probability tree: the nature decides the states of the world with associated probabilities, but according to the informative set the predictor could mistake.



Flipped probability tree: here we reverse the point of view, given the predictor ability of forecasting states of the world we associate a probability to each state of the world is really happening



Complete decisioon tree: it is as the flipped probability tree but in each decision node there is the associated payoff.

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Climate-proof Irrigation Strategy tool

The Climate-proof Irrigation Strategy tool delivers an indicator that, based on expected precipitation, evaporation, and crop irrigation needs, assesses water stress in three selected years under different climate change scenarios.

Final indicator of the climate service	Wetness1 (mm/10 days of water availability)
State of the world	«WATER DEFICIT» (Wetness1 <40mm/10 days cumulative) NO WATER DEFICIT (Wetness1 >40mm/10 days cumulative)
Scenarios	
BaU:	Present decadal value of water availability
RCP:	RCP8.5; RCP4.5; RCP2.6
Time/scale:	2030; 2050; 2080
Climate modelling exercises:	CSC_REMO2009_MPI-ESM-LR, IPSL_WRF33_CM5A, KNMI_RACMO22E_EC-EARTH, SMHI_RCA4_EC-EARTH, SMHI_RCA4_HadGEM2-ES
Hydrological models	LISFLOOD, E-Hype21, VIC421
Climate service output	Probability of water deficit: number of climate model-hydrological model combinations giving Wetness1<-40mm per RCP
Payoff	Expected production loss associated to «WATER DEFICIT» occurrence , (30% loss in production) Million euro (percentage referred to 2016 production values)
Actions	
Choose the most appropriate irrigation strategy	Action affects the coefficient of water availability directly
An action is translated in a change of:	Probability of Wetness1 < -40mm

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Data

Selected crop: **HORTICULTURAL CROPS in the Castiglione district Italy**

Basic values:

- Area (ha) 929
- Production loss (€million) in the case of water deficit (referred to 2016 production value: 6.41) 1.92

Actions:

- Sprinkler irrigation (today irrigation system)
- Drip irrigation
- Sub irrigation

	Unitary costs (€/ha)	Total costs (€million)
Sprinkler irrigation (Act1)	600	0.56
Drip irrigation (Act2)	900	0.84
Sub irrigation (Act3)	1200	1.11

	Sprinkler irrigation (Act1)	Drip irrigation (Act2)	Sub irrigation (Act3)
Water deficit	-(1.92+0.56)= -2.48	-(1.92+0.84)= -2.76	-(1.92+1.11)= -3.03
No water deficit	-0.56	-0.84	-1.11

Uncertainty

Uncertainty in BaU: How many combinations of hydrological models- climate modelling exercises forecast «WATER DEFICIT» if water availability is at today level according to each irrigation option in each year

Uncertainty in RCPs: How many combinations of hydrological models- climate modelling exercises forecast «WATER DEFICIT» if water availability changes according each climate scenario to each irrigation option in each year

BaU	Sprinkler irrigation (Act1)	Drip irrigation (Act2)	Sub irrigation (Act3)
2020	1	0	0
2050	1	0	0
2080	1	0	0
RCP8.5	Sprinkler irrigation (Act1)	Drip irrigation (Act2)	Sub irrigation (Act3)
2020	1	0.66	0.08
2050	1	0.73	0.36
2080	1	1	1
RCP4.5	Sprinkler irrigation (Act1)	Drip irrigation (Act2)	Sub irrigation (Act3)
2020	1	0.53	0.40
2050	1	0.73	0.40
2080	0.80	0.66	0.47
RCP2.6	Sprinkler irrigation (Act1)	Drip irrigation (Act2)	Sub irrigation (Act3)
2020	1	0.66	0.67
2050	1	0.50	0.17
2080	1	0	0

Evaluation

Steps in the evaluation process:

- Evaluation of Expected Monetary Values in BaU for each year;

    ➔ Choice of the irrigation system minimizing Expected Losses in BaU.

- Evaluation of Expected Monetary Values in each RCP for each year;

    ➔ Choice of the irrigation system minimizing Expected Losses in each RCP for each year.

- Comparison of expected losses;

    ➔ The difference is the value of the climate service information.

Results

Expected lossess (€ millions) adopting different irrigation systems in different years and RCPs

			1	2	3
			Sprinkler irrigation (Act1)	Drip irrigation (Act2)	Sub irrigation (Act3)
A	BaU	2020	-2.48	-0.84	-1.11
		2050	-2.48	-0.84	-1.11
		2080	-2.48	-0.84	-1.11
			Sprinkler irrigation (Act1)	Drip irrigation (Act2)	Sub irrigation (Act3)
B	RCP8.5	2020	-2.48	-2.11	-1.26
		2050	-2.48	-2.24	-1.80
		2080	-2.48	-2.76	-3.03
			Sprinkler irrigation (Act1)	Drip irrigation (Act2)	Sub irrigation (Act3)
C	RCP4.5	2020	-2.48	-1.86	-1.88
		2050	-2.48	-2.24	-1.88
		2080	-2.10	-2.11	-2.01
			Sprinkler irrigation (Act1)	Drip irrigation (Act2)	Sub irrigation (Act3)
D	RCP2.6	2020	-2.48	-2.11	-2.39
		2050	-2.48	-1.77	-1.44
		2080	-2.48	-0.84	-1.11

Results

Value of the service (€ millions) in different years and RCPs

	RCP8.5			RCP4.5			RCP2.6		
	2030	2050	2080	2030	2050	2080	2030	2050	2080
Climate service value	0.85	0.44	0.27	0	0.36	0.1	0	0. 33	0

Value of the service (€ millions) per RCPs

	RCP8.5	RCP4.5	RCP2.6
Climate service value	1.57	0.46	0.33

CLARA GRANT AGREEMENT N° 730482

Thank you for your attention.

Contact e-mail: jaroslav.mysiak@cmcc.it, francesco.bosello@cmcc.it, elisa.delpiazzo@cmcc.it

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