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A participatory systems approach to identify and quantify climate adaptation tradeoffs

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Abstract: Here I present a participatory system approach based on cognitive mapping that can be used to identify and relatively quantify climate adaptation tradeoffs. Fuzzy cognitive mapping (FCM) allows the integration of different participant views in the form of semi-quantitative cause-effect maps, each expressing their own knowledge or experience of a similar or distinctive part of a system. This particular nature of FCM allows to co-produce knowledge around a phenomenon and can be also used in the context of climate adaptation planning. To show its potential to identify and assess climate adaptation tradeoffs, I use a case study that explores heatwave impacts and adaptation options in the city of Madrid (Spain). Based on 22 individual maps elicited from agents with different backgrounds (urban planning, energy efficiency, water, green infrastructures, health, climate change…), an integrated multisectorial representation of urban heatwaves phenomena in Madrid has been obtained. In FCM, each participant interprets phenomena and connects cause and effects in very diverse manners. This information, far from being contradictory, explains the complexity of the system and provides complementary knowledge to assess impacts of different policy options. Alongside its potential as a knowledge co-production method and as a communication and learning tool, FCM allows analysis of what-if scenarios and assessment of cascading effects that would be difficult to identify otherwise. This application enables the identification and assessment of tradeoffs of policy options (so-called what-if scenarios). In the case study presented, 4 heatwave adaptation policy options are simulated: use of air conditioning, use of recycled water, deployment of green infrastructures and heat warning systems. Tradeoffs of each policy option are identified, quantified and compared. I discuss the benefits of this approach and the limitations of using this information for decision-making.

Keywords: urban resilience, tradeoffs, climate change adaptation, fuzzy cognitive mapping, systems approach, transdisciplinarity, participatory modellling.

Tradeoffs are an important component of resilience and sustainability management. Negative or positive impacts may easily arise when altering the course of a given process. From a network theory point of view, the identification of tradeoffs is even more important in highly connected system such as cities, where connectivity can be a double-edge sword: it may help to implement an action and spread its effects but, it may also hinder the agency of change, which means that unintended consequences may arise.

Systems approaches to sustainable development are now being proposed to help identifying cascading effects and also unintended impacts that may be neglected otherwise. Systems approaches are particularly useful in the case of urban sustainability research, as cities concentrate action on the ground for many of the Sustainable Development Goals (SDGs). Also, transdisciplinary approaches that consider interaction with diverse actors along the process of science co-production, are suggested to deliver sustainable solutions more adapted to the real world.

In this short paper, I would like to present the benefits of the application of a method that uses a transdisciplinary systems approach and it is therefore able to integrate and connect diverse sources of information. Fuzzy Cognitive Mapping (FCM), has proven to be useful to explore sustainability impacts of resilience and transformation and it is definitely a great tool to integrate stakeholders' knowledge and perception. In a nutshell, FCM is a semiquantitative cognitive mapping method that allows to integrate knowledge, experiences and perceptions of individuals or groups and reflects them into a map that links concepts through weighted connections. Its semiquantitative nature, allows its application for scenario building, which will be used here to identify tradeoffs of different policy options and to comparatively quantify them.

Here, I build on a previous study where, colleagues and I used this participatory systems approach to prove the emergence of new knowledge for climate change adaptation decision-making. We applied the approach for the case of heatwaves in the city of Madrid, interviewed 24 participants and elicited information regarding impacts of heatwaves and potential adaptation options. Following a step-by-step approach to guarantee transparency and reproducibility, we collected 22 individual maps that gathered 380 concepts (that participants individually perceived important within heatwave phenomena) linked through 491 weighted connections. The data (maps, concepts and connections) were treated, the terminology and scale were homogenised and maps aggregated into a single final map. The step-by-step methodology is explained here and the analysis of individual and aggregated maps can be found here.

The resulting combined map consists of 87 concepts and 295 connections (see Figure 1). Although the density was found to be relatively standard (D=0.0377), the study of the interconnections among the elements in the final map were found to be extremely important for climate change adaptation planning and policy making (see Figure 2). In modelling and mapping exercises, direct impacts of a given action or phenomenon are more easily perceived, however, undirect cascading impacts resulting from the former one, are generally not account for. The advantage of using FCM is that it connects different fields of expertise and diverse knowledge sources, thus it is able to compute cross-sectoral and/or cross-scale effects of policy options applied into a single sector (for example, the effects on health as a result of an increase in non-motorised mobility options). However, it must be noted that FCM does not account for time, i.e. results show the status of the system under a change given original conditions (t=0).
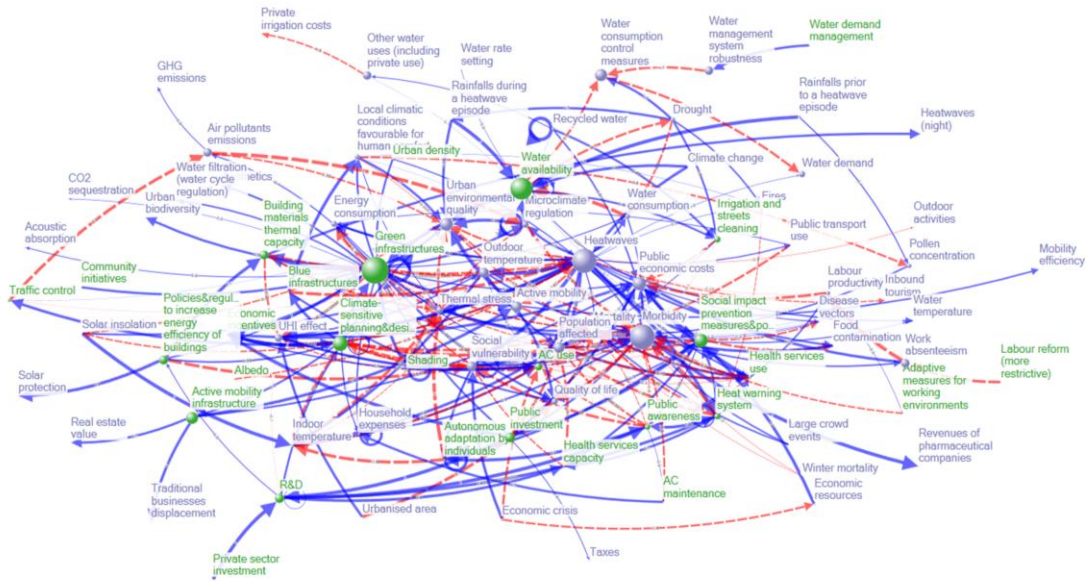
Figure 1. (a) Final map. Solid blue arrows denote positive connections; dashed red arrows denote negative connections; the thickness of the arrows denotes the strength (weight) of the connection; the size of the nodes denotes their centrality (importance) in the map. Adaptation measures identified by the participants are indicated with green nodes and text. Produced with NodeXL software

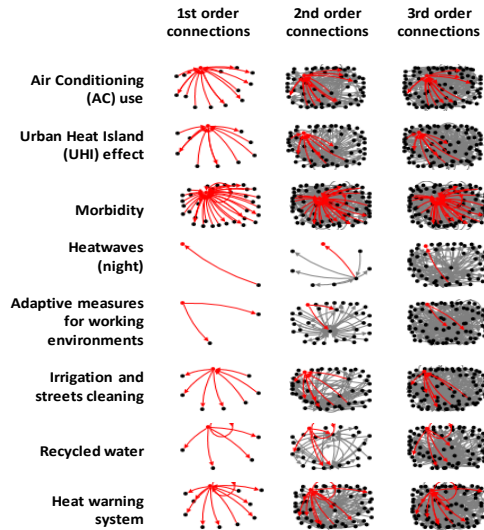(b) Source   (1)

Figure 2. (a) Interconnectedness of concepts. The graph shows levels of adjacent concepts illustrated through first-, second- and third- order connections. The red dot denotes the concept analyzed (indicated in the far-left column). The red connections reflect the first level of adjacent concepts (first-order connections).

(b) Source   (2)

To show how tradeoffs can be identified and quantify through FCM, here I test 4 different adaptation policy options (so-called what-if scenarios): (1) use of air conditioning, (2) use of recycled water, (3) deployment of green infrastructures and (4) heat warning systems. This policy options have been selected out of the 29 different adaptation strategies identified by participants. Applying a FCM scenario building equation, we will be able to observe and compare the impacts on the system (i.e. on the rest of the

elements of the system) if we apply a policy option i.e. a gradual change on one element. For example, we increase the use of air conditioning and so forth. Impacts can be negative or positive depending on first, how concepts (nodes in the maps) have been defined (see supplementary material here), and second, on our goals in relation to general premises for resilience and sustainability. In this case, we may choose to follow the SDGs. For example, if GHG emissions increase as a result of an increase in air conditioning, this can be interpreted as a negative impact for sustainability and thus as a resilience tradeoff, that in the context of adaptation to climate change, it is also recognised as a result of maladaptation.

In the following tables I show the results of the 4 what-if scenarios as a percentage of change. I quantify the relative change from a low to a high deployment scenario for the 4 options. That is, we may observe for example, how Air Conditioning decreases (Id. 2) in a 17.93% while Green Infrastructures (Id. 26; what-if scenario 3) increase from low (0) to high deployment (100%) scenario.

Table 1. What-if scenarios applied as an adaptation policy option to heatwaves in Madrid and potential impacts. Data reflects the relative change a low to a high deployment scenario. Non-significant changes have been removed. Length of the positive (green) or negative (red) change is relative to each scenario (column 1, 2, 3 and 4).

Id	Concepts	1 AIR CONDIT.	2 RECYCLED WATER	3 GREEN INFRASTR.	4 HEAT WARNING SYSTEMS
1	AC maintenance			-0.01%	0.36%
2	AC use			-17.93%	-1.59%
3	Acoustic absorption			9.53%	
4	Active mobility	-0.06%		14.48%	
5	Active mobility infrastructure			-0.04%	
6	Adaptive measures for working environments				
7	Aesthetics			16.99%	
8	Air pollutants emissions	2.65%		-6.15%	-0.01%
9	Albedo				
10	Autonomous adaptation by individuals	0.01%		-0.37%	0.56%
11	Blue infrastructures			-0.04%	
12	Building materials thermal capacity			11.11%	
13	Climate change				
14	Climate-sensitive planning&design	0.03%		-0.26%	0.03%
15	CO2 sequestration			6.59%	
16	Community initiatives				
17	Disease vectors	0.24%		-3.71%	-1.65%
18	Drought	0.02%	-0.21%	-0.15%	-0.01%
19	Economic crisis				
20	Economic incentives			-0.03%	-0.01%
21	Economic resources				
22	Energy consumption	20.34%		-30.66%	-0.06%
23	Fires	0.07%	-0.02%	-0.78%	-8.00%
24	Food contamination	0.44%		-6.61%	-2.00%
25	GHG emissions	0.15%		-0.36%	
26	Green infrastructures				
27	Health services capacity	0.01%		-0.12%	4.24%
28	Health services use	-5.84%	0.01%	-4.36%	15.13%
29	Heat warning system			-2.69%	
30	Heatwaves	8.71%		-55.22%	-0.07%
31	Heatwaves (night)			1.50%	
32	Household expenses	0.02%		5.27%	-0.06%
33	Inbound tourism	-0.21%		3.51%	
34	Indoor temperature	-35.73%		-7.26%	
35	Irrigation and streets cleaning		6.97%	0.02%	
36	Labour productivity	-0.99%		-0.11%	2.43%
37	Labour reform (more restrictive)				
38	Large crowd events				
39	Local climatic conditions favourable for human comfort	0.01%		6.78%	
40	Microclimate regulation	-0.17%		21.93%	
41	Mobility efficiency	-0.01%		1.64%	
42	Morbidity	28.90%	-0.57%	-58.21%	-53.96%
43	Mortality	-30.56%	-0.56%	-35.79%	-46.85%
44	Other water uses (including private use)		8.62%	0.01%	

Table 1 (cont.). What-if scenarios applied as an adaptation policy option to heatwaves in Madrid and potential impacts. Data reflects the relative change a low to a high deployment scenario. Non-significant changes have been removed. Length of the positive (green) or negative (red) change is relative to each scenario (column 1, 2, 3 and 4).

	What-if scenarios	1	2	3	4
Id	Concepts	AIR CONDIT.	RECYCLED WATER	GREEN INFRASTR.	HEAT WARNING SYSTEMS
45	Outdoor activities	-0.10%		1.66%	
46	Outdoor temperature	10.97%		-20.06%	-0.10%
47	Policies&regulations to increase energy efficiency of buildings				
48	Pollen concentration			-1.89%	
49	Population affected	-3.64%	1.75%	-38.21%	-55.18%
50	Private irrigation costs		-1.79%		
51	Private sector investment				
52	Public awareness	0.01%		-0.12%	5.42%
53	Public economic costs	-0.04%	0.42%	0.38%	0.10%
54	Public investment	0.03%	0.06%	-0.18%	-0.16%
55	Public transport use	0.19%		-2.83%	
56	Quality of life	-0.02%		7.34%	0.22%
57	R&D			-0.01%	-0.01%
58	Rainfalls during a heatwave episode		-0.02%	-0.01%	
59	Rainfalls prior to a heatwave episode				
60	Real estate value				
61	Recycled water				
62	Revenues of pharmaceutical companies	0.13%		-0.73%	-0.55%
63	Shading			22.53%	
64	Social impact prevention measures&policies	0.07%		-0.98%	4.58%
65	Social vulnerability	1.07%		-38.46%	-6.13%
66	Solar insolation	-0.01%		0.08%	-0.01%
67	Solar protection				
68	Taxes		0.01%	-0.02%	-0.01%
69	Thermal stress	14.72%		-63.02%	-0.53%
70	Traditional businesses displacement			-0.01%	
71	Traffic control			-0.04%	
72	UHI effect	25.50%		-46.64%	-0.22%
73	Urban biodiversity			19.03%	
74	Urban density				
75	Urban environmental quality	-0.01%		1.05%	
76	Urbanised area				
77	Water availability	-0.05%	0.44%	0.30%	0.02%
78	Water consumption	0.23%	0.02%	7.90%	
79	Water consumption control measures	0.03%	-0.29%	-0.20%	-0.02%
80	Water demand	0.12%	0.04%	-1.87%	
81	Water demand management				
82	Water filtration (water cycle regulation)			14.73%	
83	Water management system robustness				
84	Water rate setting				
85	Water temperature	0.23%		-3.45%	
86	Winter mortality				
87	Work absenteeism	0.03%		-0.58%	-0.43%

As the reader may note, data shown above is extremely thought-provoking and may be exploited and assessed in many different ways. Here, I will only discuss the most significant outputs. For example, the effect on the system of the different what-if scenarios is in cases restrained (1 and 2) and some times uncontainable (3 and 4). Particularly, the increase in green infrastructures in the city of Madrid, appears to have an effect over more than 75% of the system. On the contrary, only 20% of the system is affected by an increase in the use of recycled water (51% in the case of air conditioning and 42% in the case of heat warning systems). This means that, according to participants in this study, green infrastructures are highly connected with other sectors in Madrid, and although it is a very popular adaptation option, because of its flexibility and associated co-benefits, potential negative impacts should be well-account for. However, have green infrastructures negative impacts on sustainability? I did not find any in this

experiment. Green infrastructures (What-if scenario 3) followed by Recycled Water (2) and Heat warning systems (4) have been found to be the best sustainable options for climate change adaptation so far, as compared to Air conditioning (1). Let's see below.

What-if scenario 1: Increased use of air conditioning. The most important tradeoffs in the use of air conditioning are the increase in outdoor temperature (Id. 46) (which is connected with the Urban Heat Island (UHI) effect - Id.72, and the increase in thermal stress – Id. 69). The increase in energy consumption (Id. 22) is also an important consequence and also the increase in morbidity (Id. 42). Interestingly, mortality is expected to decrease (Id. 43) as a result of a decrease in indoor temperature (Id. 34). Read this way, air conditioning might be a useful adaptation option to face urgent health issues but may have important negative effects in the medium and long term.

What-if scenario 2: Increased use of recycled water. According to combined knowledge of participants, recycled water use, for example, does not lead significant tradeoffs. It may help to keep public hygiene during heatwaves and accompanying droughts as it helps to keep services related to irrigation and streets cleaning (Id. 35). It also helps to distribute water to other uses (Id. 44) more critical during these phenomena (e.g. drinkable water).

What-if scenario 3: Increase of green infrastructures. Green infrastructures are highly connected and affect many elements in the system. The account for many positive effects such as: reduction of outdoor temperature (Id. 46) and thus a reduction in thermal stress (Id. 69) and UHI effect (Id. 72). In general, the effect of heatwaves (Id. 30) reduces as green infrastructures help to reduce the number of affected population (Id. 49) and in general social vulnerability (Id. 65). They support microclimate regulation (Id. 40), provide shade (Id. 63), acoustic absorption (Id. 3) aesthetics (Id. 7) and help to increase or maintain urban biodiversity (Id. 73) that provides attractive spaces to promote active mobility (Id. 4). Green infrastructures help to decrease indoor temperature (Id. 34) and thus, air conditioning use (Id. 2), which also contributes to reduce energy consumption (Id. 22).

What-if scenario 1: Increase in efficiency of heat warning systems. Heat warning systems, are here perceived as the most controllable and effective adaptation option: they help to increase awareness (Id. 52) and thus, reduce morbidity (Id. 42) and mortality (Id. 43) and also reduce the potential for fires (Id. 23). However, awareness may end in an increase of health services use (Id. 28), which should be carefully monitored and adequate measures should be put in place if that happens.

Green infrastructures seem to be the adaptation option that provides more co-benefits (i.e. positive tradeoffs). In the interviews, though, negative impacts were mentioned such as allergies (pollen) and economic costs derived from green infrastructures maintenance (specially trees). However, these were too specific (the scale of the map is higher, i.e. it accounts for morbidity and does not provide information on specific diseases) and the general positive impact on health and public economy masks this information. This highlights the importance of the methodological decisions regarding the development of the aggregated final map and the relevance of its implementation through transdisciplinary projects where scientific outputs are co-produced and thus tailored to fit stakeholders needs.

As shown above through the simulation of these 4 adaptation policy options, data collected through transdisciplinary systems approaches is highly relevant for resilience and sustainability management and decision-making. In the specific context of this study, it is especially useful to stress the fact that climate change adaptation is not positive per se and may generate cascading and unintended impacts on other elements at different scales or belonging to different sectors. These unintended impacts or tradeoffs

might be positive (so called co-benefits of adaptation) or negative (so-called maladaptation), nonetheless they should be carefully assessed to decide whether the policy option is worthwhile. Because urban management and policy is nowadays siloed into different often uncommunicated management units within the main local administration, this information should be useful in participatory forums to facilitate stakeholders recognising interconnectedness among their management areas which may hopefully end with the creation of communication channels or the improvement of existing ones. Creating these science-policy bridges will unquestionably help to overcome significant barriers in the progress towards sustainable development in urban areas.

Acknowledgments

Conflict of Interest

The author declares no conflict of interest.

No references for the short papers but hyperlinks within the text