How to enhance urban resilience: a decision support approach based on input-output modeling, geographic information system and participative processes.

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1. INTRODUCTION

In this paper, we develop a decision-support approach to help stakeholders to implement resilience in urban areas regarding the perturbations caused by heat waves in France. Resilience is a strategy to reduce vulnerability and to quickly rebound after a disaster. It can be achieved by technical and governance solutions as well as cultural changes. Three categories of resilience can be identified at three different time *t* after a disaster occurred:

- t_1 when the disaster begins: resilience is achieved by resistance (e.g. reducing material damages),
- t_2 just after the disaster happened: resilience is achieved by absorption of the impact (e.g. maintaining high connectivity between human organizations)
- t_3, *a* longer time after a disaster happened: resilience is achieved by recuperating, i.e. coming back rapidly to an operational situation.

Our approach to help stakeholders achieving resilience relies on three methods: input-output (I-O) modeling, participative decision processes and Geographic Information System (GIS). The use of these tools is framed by a participative process named INTEGRAAL. The participative process is made of five steps. In the three first steps, local stakeholders are consultants that help scientists to understand urban resilience issues occurring in the local area under study, the city of Mantes-la-Jolie (North Paris). In the last steps, stakeholders are deciders and select political measures based on social and scientific knowledge built in first steps. The five steps and the use of the three tools are detailed in Section 2.

2. METHOD

2.1. Step 1: identification of the scope of the issue

The first step of INTEGRAAL consists in identifying the scope of the issue, i.e. geographic limits of the area concerned by the issue, the list of stakeholders involved, their goals and their cultural, social and economic activities. A literature review and meetings with stakeholders help to identify the scope.

2.2. Step 2: organization of the issue

The second step aims at organizing the problem of social choice based on a three axes structure : *i*) various stakeholders, *ii*) evaluation criteria also called "performance issue" (e.g. keep stable the provision of urban services, viability of economic activities), and *iii*) scenarios of possible measures aimed at improving resilience of urban systems (e.g. technical options, governance changes). This step relies on a detailed study of the area defined in Step 1 that involves interviews of stakeholders listed in Step 1 and a literature review.

2.3. Step 3: representation of the issue

The third step consists in mobilizing tools for representation of the issue and the impact of resilient scenarios drawn up in previous step. In Step 3, stakeholders are to be considered as consultants

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which ensure that tools and scenarios of measures properly describe their problems. The tools used are spatial modeling (GIS), hybrid I-O models and vulnerability trees (Figure 2). Vulnerability trees (Figure 1) are a kind of tool that are particularly interesting in resilience analysis to identify where are the vulnerabilities of urban systems and which economic activities might suffer from impacts caused by perturbations. Subsequently, a hybrid I-O model can be used to estimate direct plus indirect economic and ecological impacts of perturbations caused to economic activities identified in the vulnerability tree. For the assessment of the performance of the resilient measures proposed in the scenarios, resilient scenarios are compared to a *business-as-usual* scenario (without measures).

a) Vulnerability trees: a tool for the analysis of economic, ecological and social impacts

The identification of economic, ecological and social impacts of a perturbation can be analyzed with vulnerability trees. Their construction relies on analyses of official reports based on past experiences of perturbations that happened in other cities (parliamentary reports, expert analyses, press articles, etc.). Vulnerability trees offer a helpful tool to identify vulnerabilities that reduce urban resilience. Vulnerabilities can be categorized into four types: failing interactions between urban stakeholders (organizational vulnerability), inappropriate technologies (technical vulnerability), unsafe natural conditions (biophysical vulnerability) and social culture and mentality (social vulnerability). Once failing vulnerabilities have been pointed (Figure 1), it becomes easier to think about measures that could help to restructure the organization between urban stakeholders, to adapt technologies and infrastructures, to modify biophysical conditions and to initiate mentality and cultural changes in order to improve urban resilience.

Figure 1 illustrates our case study: heat waves (biophysical vulnerability) induced by climate changes generate an increase in needs for air conditioning in building that are poorly insulated against heat (technical vulnerability). This causes a rise in electricity consumption. In parallel, nuclear power plants and hydroelectric plants are vulnerable to low levels of rivers occurring during extreme heat events (biophysical vulnerability). Nuclear power plants cannot operate at full capacity due to the lack of cooling water while hydro-electrical plants lack of water to operate their turbines. Both vulnerabilities, the rise in electricity consumption and the drop in electric production, generate a scarcity in electricity supply on the network. Several industries cannot be alimented in energy and are constrained to reduce or even to temporarily stop their production to other companies and customers (organizational vulnerability). Vulnerability trees help to identify these chains of cumulative failures and consequently to identify what kind of solutions must be investigated (e.g. investment programs in energy production systems non-depend from water resources and programs of reduction of electricity consumption during heat waves in least critical economic sectors).

b) Input-output models: a tool for the analysis of direct plus indirect impacts

Once economic, ecological and social impacts have been identified with the help of vulnerability trees, an I-O model is used to quantify the part of impacts which is economic (Figure 2). An I-O model is a macro-economic model made of matrices and linear equations that represent the way economic sectors exchange between themselves raw materials and semi-finished products or services to fabricate their own final product or service that will be sold to final consumers (e.g. to households). The I-O model is used to simulate the chain of cumulative failures identified in vulnerability trees starting from the economic sectors that are directly impacted by heat waves (industries that suffer from electricity shortage, for instance the electronic sector) and going backwards the economic supply chain to quantify indirect impacts on all providers of these industries. For instance, the computer sector might be indirectly impacted by a drop in the provision of electronic components from electronic industries which suffer a shortage in electricity supply. The quantification of such direct and indirect economic impacts is of great interest for the quantification of business-as-usual (BAU) scenarios in which no resilient measures are implemented.

In a second stage, the I-O model also simulates economic and ecological impacts of resilient measures. Positive effects are estimated by comparing results of resilient scenarios with BAU scenarios. The avoided costs of damages are expected to make resilient scenarios more attractive in economic terms than BAU ones if implementation costs of resilient measures are not excessive. However, the I-O model also shows the amount of pollutant and residual waste emitted by the economy (e.g. green house gases) as well as natural resources extracted (e.g. water extraction) (Figure 2). This helps to verify if resilient scenarios do not lead to increase the pressure of the economy on the ecosystem (e.g. infrastructures constructed to increase resilience might increase polluting emissions). In such case, it is important to wonder if the scenario is truly resilient.

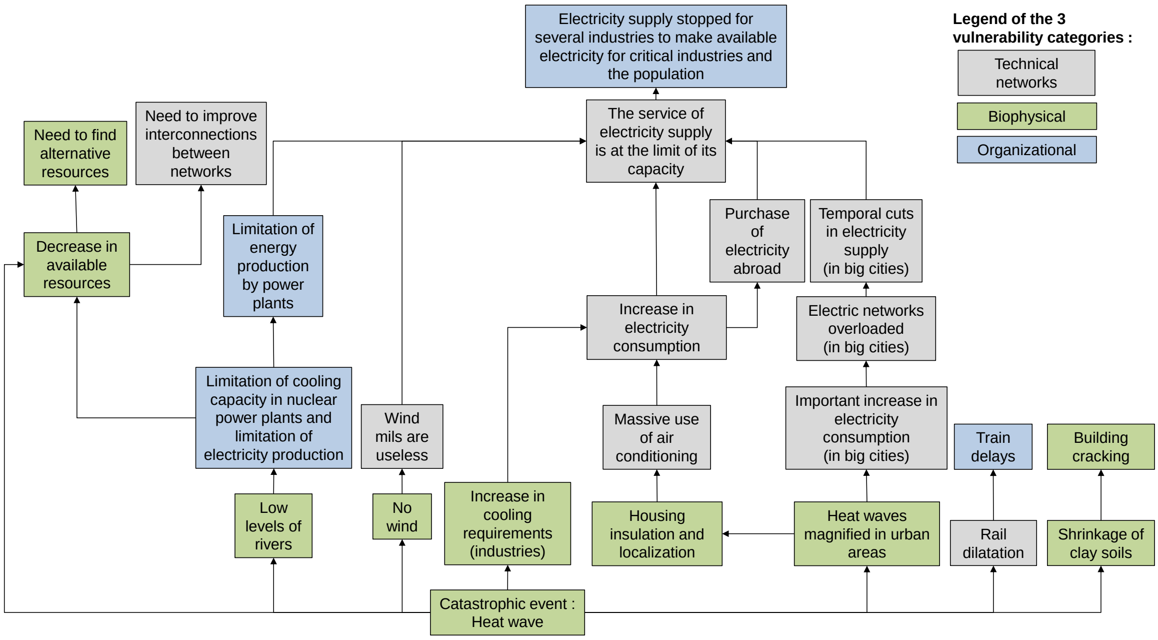

Figure 1. Vulnerability tree describing the chain of cumulative failures caused by the 2003 heat wave that lead to a drop in electricity production in France (Resilis, 2011).

c) Geographic Information System (GIS): a tool for vulnerability identification and scenario impacts representation

GIS is used in a first stage to study the potential feedback impact of an economy-induced modification of the ecosystem on economic activities themselves. To study the feedback impact, GIS is used to identify vulnerable areas (biophysical vulnerabilities in Figure 2) where potential causes of economy slow down could be located, causes originating from ecosystem modifications. This is achieved by crossing maps in a GIS that show areas exposed to heat waves and areas of industrial activities supplied in electricity produced by hydro-electrical and nuclear power plants. These areas are vulnerable because hydro-electrical and nuclear productions are reduced during heat waves due to a lack of water.

Another use of GIS is not anymore to analyze causes of economic slow down induced by ecosystem modifications but to represent economic consequences of these modifications on the economy and ecosystems (see in Figure 2 ecological impacts, direct economic vulnerabilities and indirect economic vulnerabilities). In other words GIS is used here to offer a spatial representation of impacts of scenarios of measures and BAU.

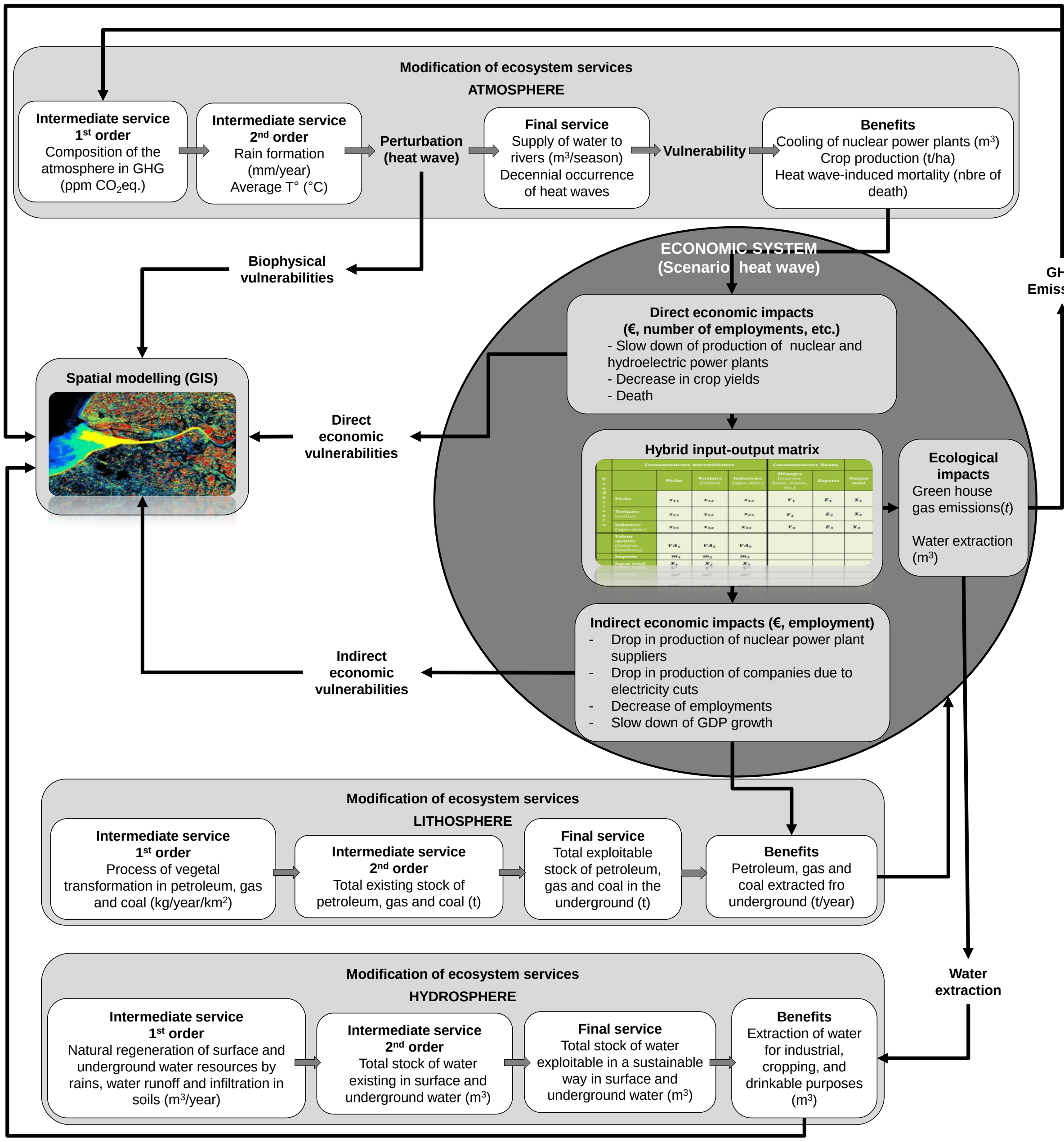

Figure 2. Place of input-output models and GIS in a disaster modeling that includes biophysical and economic impacts.

2.4. Step 4: deliberation

The fourth step consists in mobilizing stakeholders for a multi-criteria, multi-scenario, multi-stakeholder assessment of resilient measures proposed in scenarios in Steps 2 and 3. The assessment is carried out through a deliberation process with stakeholders organized according to the structure defined in Step 2. In the deliberation process, each stakeholder gives a score to each scenario according to each criterion based on the information given in Step 3. The score can be given based on a color code: green for good performance, yellow for poor performance and red for unacceptable performance (Figure 3). In the end, the deliberation process makes trade-offs more apparent and initiates a negotiation process which is inevitable in the framework of uncertain and controversial issues such as urban resilience.

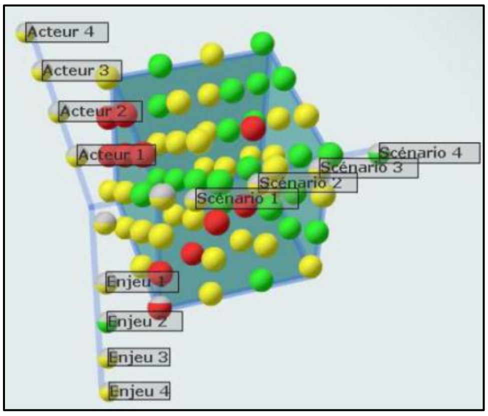

Figure 3. Deliberation matrix (C3ED and Fondaterra, 2007). Note: the deliberation matrix is built on a three axes structure. Axe 1 shows various stakeholders (*Acteur* in French), axe 2 shows various performance issues (*Enjeu* in French) and axe 3 shows the various scenarios (*Scénario* in French).

2.5. Step 5: communication of results

This step aims at reporting to stakeholders as well as to the general public the results of the multi-criteria, multi-scenario, multi-stakeholder assessment. Recommendations are also made in this step. If the results generate more discussions, it is possible to return to Step 1 and carry out another iteration of all the five steps of the INTEGRAAL deliberative approach. In this new iteration, other tools can be chosen to represent resilient measures and other scenarios can be drawn up in order to find a path towards conflict solving. The final aim is to pass from scientific research to decision with the participation of research team and stakeholders altogether.

3. Results and discussion

This paper proposes a methodological approach to build a decision-support tool that helps stakeholders to implement resilient conditions. In Step 3, maps are used at two different stages. In the first stage, maps are built from statistical data as well as from stakeholders themselves. GIS are used to cross maps. That helps to identify vulnerable areas. Once they are identified, scenarios of resilient measures are built in a participative process to reduce vulnerabilities. Their impact is simulated with an I-O model. In the second stage, the results given by the I-O model are entered into a GIS in order to produce maps that help stakeholders to visualize and spatialize information. This should make easier the ownership and the understanding of the issue by stakeholders inside the participative decision process. The advantage of I-O models for participative processes is their capacity to identify and quantify trade-offs. This is an important asset because multi-criteria evaluation techniques, if they cannot solve all conflicts, can help to provide more insight into the nature of these conflicts by making the trade-offs in a complex situation more transparent to decision-makers.

3. References

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