International Organization
for
Chemical Sciences in Development

Technical Resource

Introducing the SOCME tool for systems thinking in chemistry

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The IOCD action group, *Chemists for Sustainability*[1] (C4S) focuses on the role that chemistry must play in contributing to a more sustainable future,[2] In an article in 2016, the group emphasised[3] the need for chemistry to adopt systems thinking (ST)[4] and cross-disciplinary[5] working – as a means to reorient chemistry[6] as a discipline and to optimise the contributions it can, and must, make to sustainable development.[7] Subsequently an international project (2017-2019) on the infusion of systems thinking into general chemistry education (STICE) was established by IUPAC,[8, 9] also supported by IOCD and co-chaired by Peter Mahaffy and Stephen Matlin.

Systems can be complex and thinking about them can be very challenging. A number of visualization tools are available to depict and assist in understanding systems and their interactions. These include stock and flow diagrams, causal loop diagrams, behaviour over time graphs, concept maps, systemigrams and object–process methodology. They cover a range of approaches in terms of complexity, the formality of rules that apply to their use and the amount of training required to understand and apply them.[10]

In the course of developing the STICE project, an intermediate level tool was sought that would be suitable to help introduce ST into general chemistry. The required tool would assist in portraying the key features of components of a system and their dynamic interactions, would allow ease of drawing with commonly available graphic programmes, be suitable for incremental extension and build-up, and be adaptable for both intra- and inter-system relationships and effects. The traditional Concept Map (CM) has a number of these features but it required some extensions in approach to increase flexibility and range – and, in particular, to make more explicit the system dimension by highlighting the presence of and the functions and interactions between sub-systems. The tool developed to achieve this was the Systems-Oriented Concept Map Extension, SOCME.[11] The SOCME tool can aid in exploring, understanding and depicting both within-system and cross-system interactions and in managing complexity.[12]

Key features of the SOCME approach can be seen by comparison with the CM tool, taking the biogeochemical flow of CO_2 as an example. Pioneered by John Novak[13] in the 1970s and 1980s, the CM approach (Figure 1) uses boxes with Concept Labels, which can be objects, ideas or effects, and Arrows with Descriptions to depict the relationships among the Concept Labels. There is generally a flow of effects progressing down the map.

The SOCME for biogeochemical flow of CO_2 begins (Figure 1) with a depiction of the Core Subsystem, which acknowledges that production of CO_2 through human activities is substantially raising levels of the gas in the atmosphere. On the input side, adding the Anthropogenic Generation Subsystem brings consideration of the major sources of CO_2 and the chemistry involved; and questioning about how these CO_2-generating activities might be reduced or substituted – and what the consequences would be. On the output side, adding the Ocean Interaction Subsystem leads to discussion about how CO_2 becomes dissolved, the chemistry of carbonic acid solutions and implications for the ocean biosphere.

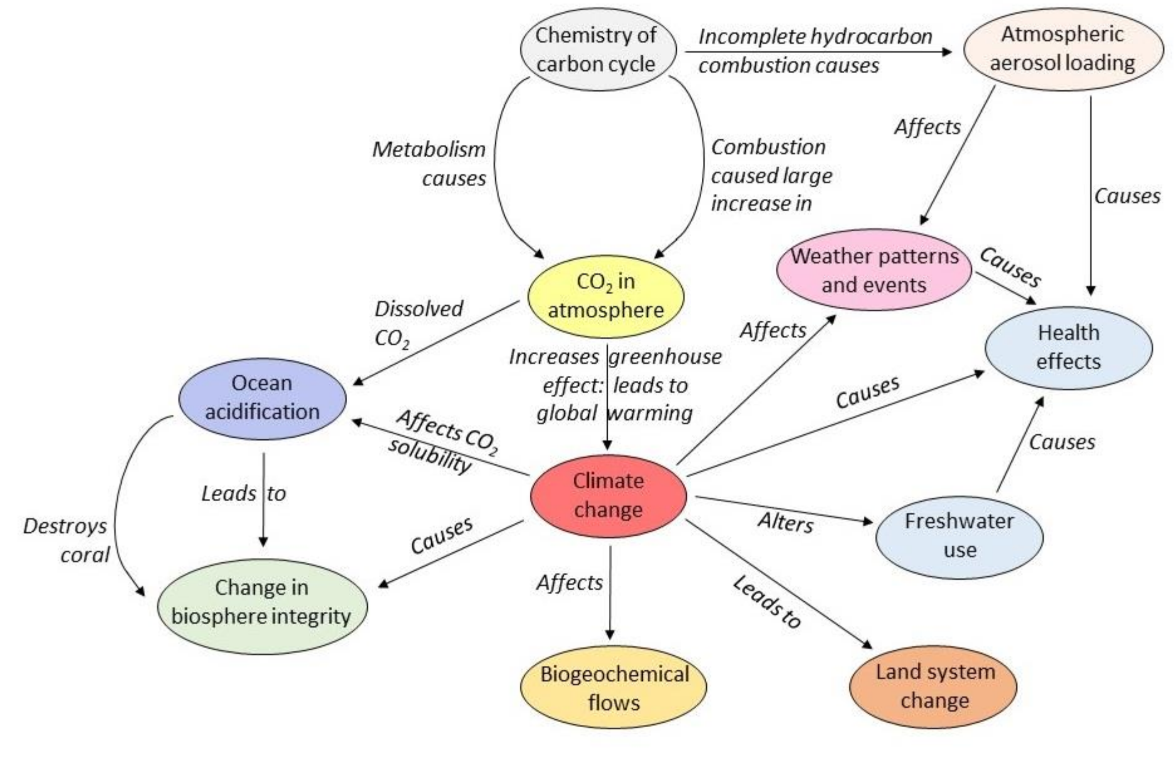

Figure 1 Concept map illustrating biogeochemical flow of CO_2

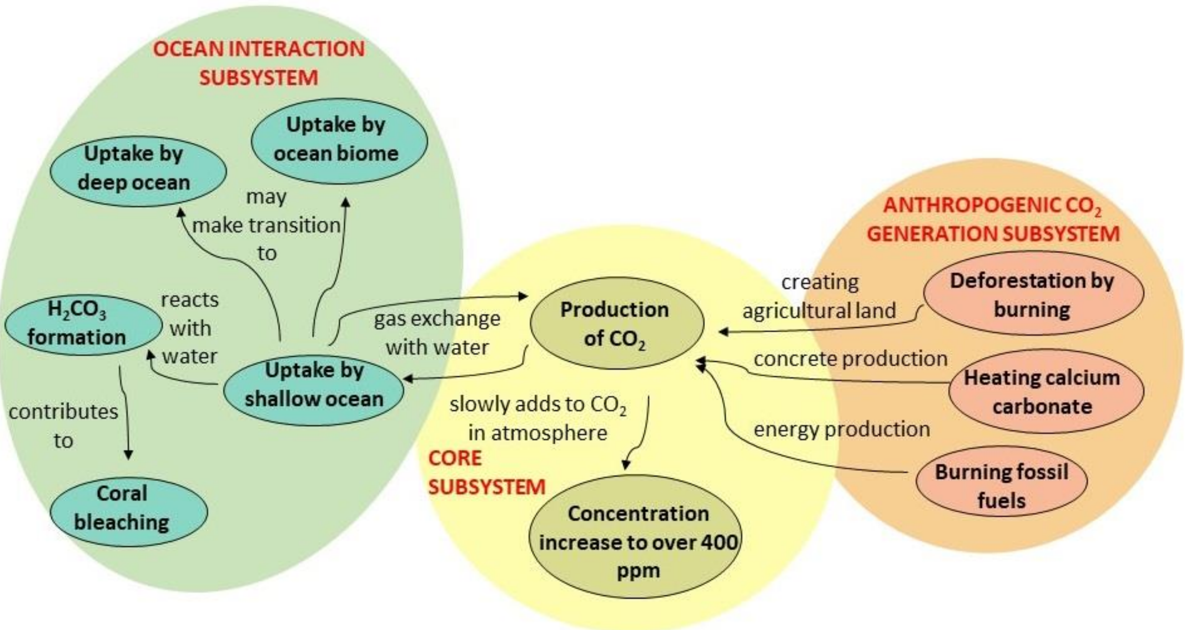

Figure 2 SOCME illustrating biogeochemical flow of CO_2

Development of the SOCME begins with the Core Subsystem which acknowledges that production of CO_2 raises its levels in the atmosphere. The Anthropogenic Generation Subsystem is then added to identify specific sources of CO_2 and the Ocean Interaction Subsystem is added to consider the results of CO_2 dissolution in water.

Further consequences can be explored (Figure 3). On the environmental side, the Land Interaction Subsystem can be considered. CO_2 is taken up and/or emitted by diverse organisms, including plants and animals, involving a wide range of metabolic and respiratory process – all affecting to the dynamic level of atmospheric CO_2. Exploring this subsystem can lead to examination of the impacts of human activities such as deforestation and agriculture. On the production side, consideration of the Human Mitigation Subsystem provides an avenue to explore issues related to fossil fuels and alternative, sustainable forms of energy that can reduce CO_2 generation and the chemistry of carbon capture and storage processes that may potentially prevent CO_2 release and/or lead to recapture of CO_2 that is already in the atmosphere.

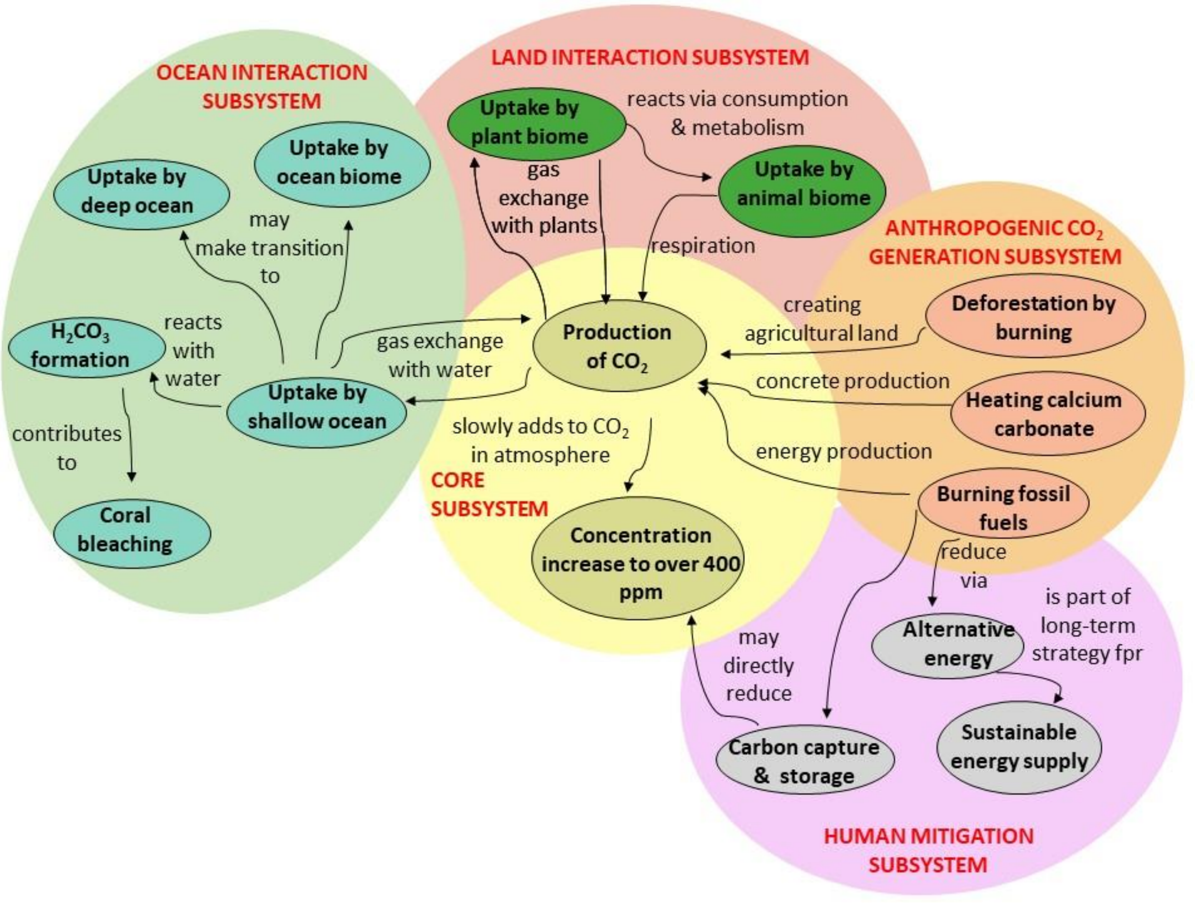

Figure 3 **SOCME illustrating biogeochemical flow of CO_2**
Successive additions of the Land interaction Subsystem and the Human Mitigation Subsystem facilitate discussions about further environmental impacts and about ways to reduce CO_2 emission or to recapture CO_2 directly during production or subsequently from the atmosphere.

Discussion of carbon capture and storage (Figure 3: Human Mitigation Subsystem) can be further extended by considering the techniques for carbon sequestration and the comparatives merits of alternatives for either permanent storage or for further use of the sequestered carbon compounds as feedstocks in the Industrial Use of CO_2 Subsystem (Figure 4). Further implications of the prevailing levels of CO_2 in the atmosphere that result from all the dynamic changes taking place can also be explored by looking at the physical chemistry of energy absorption and release by gaseous molecules in the Climate Change Subsystem.

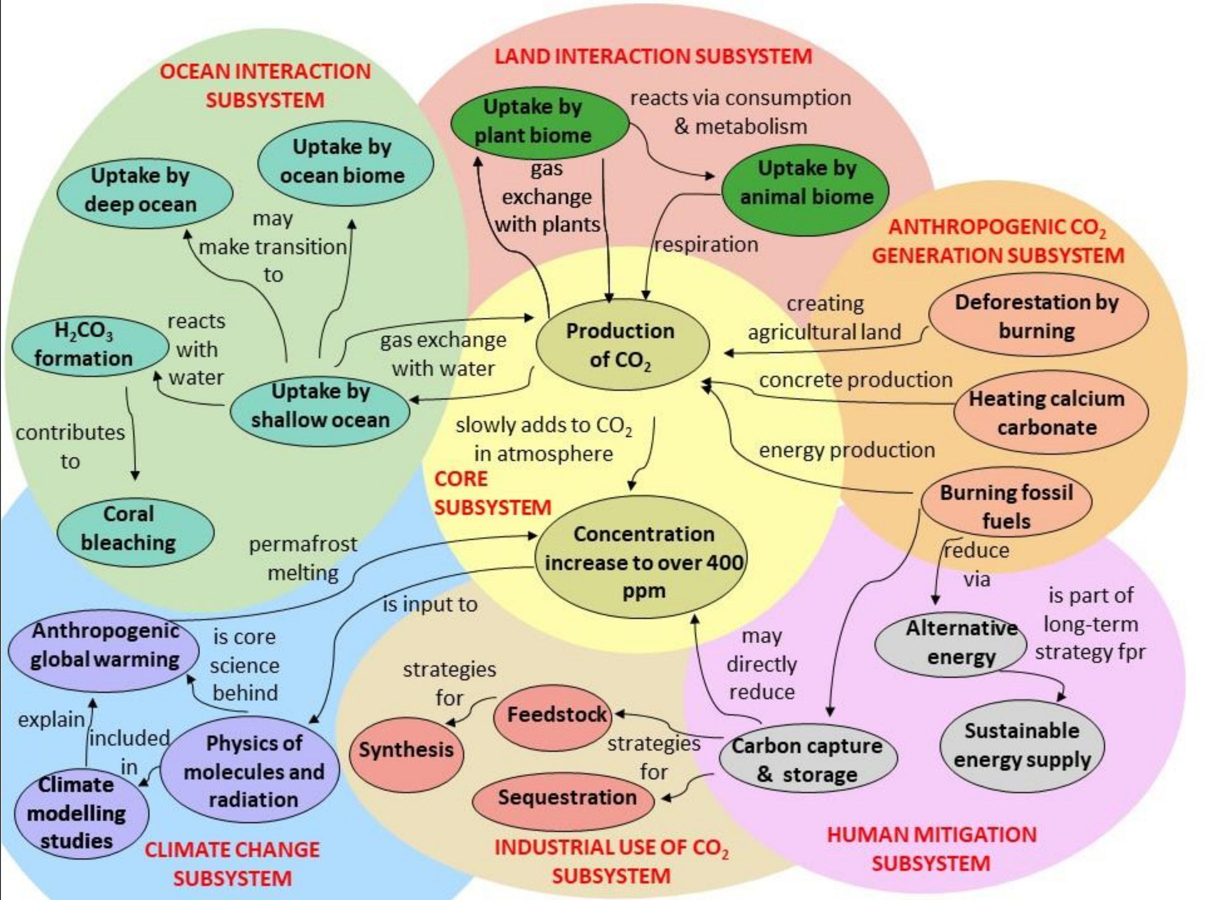

Figure 4 **SOCME illustrating biogeochemical flow of CO_2**
Successive additions of the Land interaction Subsystem and the Human Mitigation Subsystem facilitate discussions about further environmental impacts and about ways to reduce CO_2 emission or to recapture CO_2 directly during production or subsequently from the atmosphere.

Comments

The example of the SOCME illustrating the biogeochemical flow of CO_2 indicates a number of the key features of the utility of this visualization tool.

- The drawings were constructed using PowerPoint, which means that they can readily be presented step-by-step, item-by-item, as part of teaching classes or discussion or research seminars. Individual subsystems can be given increased attention by adding more detail or supplementary slides, or omitted entirely if they are irrelevant to the focus of a particular discussion.
- The division into subsystems is a stimulus to learning, discussion and research by helping to identify and expand boundaries and provoke "what if?" questions, such as: "what if we could eliminate the burning of fossil fuels and use only carbon-neutral energy sources (which?): how would this impact the total level of CO2 in the atmosphere?"; and "what if we could capture all CO_2 generated by industrial processes (how?): how would we use the captured carbon in ways that would not ultimately lead to its release as atmospheric CO_2?"

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