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Using qualitative reasoning to model life cycle assessment of wind energy

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Abstract

Energy is an essential ingredient of socio-economic development. Wind energy is ubiquitous, renewable and can help in reducing the dependency on fossil fuels. Wind is an indirect form of solar energy and is always being replenished by the sun, which causes differential heating of the earth's surface. Wind energy is clean and because it is free provides the ultimate in energy independence. Wind has emerged as a leading source of energy, in part because it is considered to be environmentally sustainable and has a number of advantages over most other energy sources. Wind farms require much shorter planning and construction time than fossil fuel or nuclear power plants. Wind generators are modular (more turbines can be added if demand grows) and have in their life cycle low fuel costs which means lower air emissions. This view point makes some key elements to move forward in this debate: the construction, implantation and operation steps, and how this knowledge could be represented, shared and learned by beneficiaries' communities in education and licensing processes.

This work presents *Wind Power*, a qualitative simulation model representing the commodity chain of wind farm and its energy production in a qualitative view of the Life Cycle Assessment. The model was built with Qualitative Reasoning techniques, which has been successfully used to model ecological systems (see the special issue on Qualitative Reasoning of *Ecological Informatics* Volume 4, Issues 5-6, pages 261-412, November-December 2009), and implemented in the DynaLearn workbench (www.dynalearn.eu), a software which is already in testing and evaluate phases. An important advantage of the Qualitative Reasoning approach for handling conceptual knowledge is the ability to capture information about both systems' structure and behaviour, including the notion of causality. Knowledge is represented by combining a set of model ingredients. Among them, a central ingredient is the *entity*, which is used to represent the physical objects or abstract concepts that define the system. The whole qualitative model is built around entities. Relevant entity properties that may change under the influence of processes are represented as *quantities*. Relations between quantities include causal dependencies of two types: *direct influences* (I+ and I-) and *qualitative proportionalities* (P+ and P-). Direct influences represent *processes* and are the initial cause of change in the system. The effects of processes are propagated via proportionalities to the rest of the system. Combined, these primitives build up causal chains.

The qualitative modeling workbench in DynaLearn consists of six learning spaces (LS) where the user can build models of increasing complexity, spanning from simple concept maps to the full range of functionalities provided by Garp3. Current version of the Wind Power model is implemented in LS1 (concept map), LS2 (basic causal model), LS3 (basic causal model with stategraph), and LS4 (causal differentiation).
The model aims to answer the following questions:
(a) How the conversion of energy from the sun in wind power is performed?
(b) How air movement is produced?
(c) How kinetic energy of the wind is transformed into electric energy in the wind plant?

Initial ideas involving the fundamental mechanisms involved in electricity generation from the air movement are organized (LS1) and further developed in a basic causal model (LS2). At this level, a simulation shows only trends: as only the derivative of the quantities are represented, possible qualitative values are {decreasing, stable, increasing}. The model shows that solar energy is unequally distributed in the atmosphere and creates regions with differences of air pressure. This unbalanced situation generates the air flow that is captured by the wind turbines. Kinetic energy is transformed into mechanical energy and finally in electricity, further used in industrial and domestic activities. In LS3, this model is improved with the representation of possible magnitude values (for example, the amount of *kinetic energy*, *mechanic energy* and *electric energy* can assume the values {zero, low, medium, high}). Simulation shows state transition and the system behaviour is better captured. Both in LS2 and LS3 causal relations are represented as arrows identified by the signs [+] and [–], and these bare dependencies are not enough to resolve ambiguous situations or to express inequality relations. From this point of view, LS4 represents a big leap, as causal relations are differentiated by means of the use of direct influences (to capture processes) and qualitative proportionalities. These two types of causal dependencies allow for representing complex knowledge, for example, knowledge required to calculate the air flow based on the difference of air pressure in two regions, and to introduce in the model feedback mechanisms that may control the system behaviour.
While simulations in LS2 are limited to the calculation of derivative values and in LS3 state graphs are produced (to show state transitions and behaviour paths through sequencial states) because of magnitude values, LS4 allows for initial scenarios describing unbalanced situations that may drive complex system behaviour that eventually ends up in a balanced situation. Such simulations allow the user to inspect the system behavior in various real-world or experimental situations.

The model can effectively be communicated to learners, as shown in previous studies about using qualitative models in science education. The diagrammatic approach, the explicit representation of causality and the possibility of inspecting all the possible behaviors improve learners understanding of the system. Ongoing work involves the development of didactic material to assess the potential of the wind power use, with minor impacts on the environment. Models and additional materials will be used to explore the capabilities of DynaLearn software in educational contexts.

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For further information, visit http://www.DynaLearn.eu