SUMMARY

System Dynamics Modelling originates in the World Model, which was developed for the Club of Rome by the late ‘60s (Forrester, 1971). A system dynamics model captures the dependencies between the state variables which drive the dynamic behavior of a system. This makes it possible to analyze different combinations of scenarios and policy choices in a coherent manner, and determine the mid- and long-term impacts of the different alternatives. Therefore, system dynamics models are very useful for supporting long-term prospective studies and policy analyses. The purpose is to identify the “tipping points” which cause the system to change its behavior significantly, for example from an equilibrium to a non-equilibrium state, rather than obtaining an accurate prognosis of a system’s behavior in all detail. At the same time a system dynamics model provides a practical analytical framework to support the integration between relevant themes such as mobility, energy, demography, environment, agriculture etc. and the corresponding computing models. The causalities of the system can be described by means of thematic models in case more profundity and detail are required. The 4-step methodology (Op ‘t Eyndt, 2011), which has been initiated in the meantime, is aimed at supporting the Flemish environmental policy by means of an approach based on four steps:

1. A qualitative systems analysis to identify the relevant themes, problems, causes and actors etc., relate these to one another at the main level of analysis, and formulate story lines for the different world views.
2. Quantitative system dynamics modelling to process these story lines at the main level of analysis.
3. Thematic deepening by modelling the key components of the system dynamics model resulting from step 2.
4. Verification of existing and planned policy options for the given objectives by means of the models resulting from step 3.

The idea is to improve the exchange of data between the thematic models, which have been deployed in earlier prospective exercises, by means of a system dynamics model which describes the “System Flanders” at the main level of analysis.

To put the 4-step methodology into practice the Flemish Environment Agency, department Environmental Reporting, began a feasibility study in collaboration with the Flemish Institute for Technological Research (VITO). The goal was to examine the boundary conditions for such a system dynamics model and apply these to assess the “model fit” or extent to which thematic models could be fitted in a dynamic system model.

The thematic issues considered include climate (change), demography, economy, agriculture and food, energy, mobility, air quality, water, ecology, and the use of material and raw resources. Experience tells us that a direct, “bottom-up” coupling of models often leads to overly complex systems which are difficult to maintain and lack flexibility. This significantly reduces the transparency and usefulness for end users. Models can differ considerably in the extent to which these can be fitted into a systems model, amongst other things because the level of detail in the description of processes and choice of variables complicate the connection at the system level of analysis, or because the dependency on reference data hampers dynamic application. A literature survey of the existing system dynamics models and prospective studies related to sustainability was first conducted to develop a generic procedure for examining the model fit of thematic models. The results were used to translate the typical characteristics of system dynamic models into design criteria and boundary conditions for system dynamics modelling. The criteria which were taken into account include:

- the prospective nature;
- earlier application of the subsystems, state variables, processes, parameters etc. in acknowledged qualitative, prospective studies related to environmental and ecological policy;
- the policy indicators and measures which were to be taken into consideration;
- the level of abstraction and aggregation (in terms of the state variables and causalities);
- the internal consistency of the system;
- the environmental sectors and themes to take into consideration;
- the time horizon and resolution used;
- the exogenous, driving factors;
- calibration and validation (sensitivity analysis);
- the need and way to include spatial differentiation.

Next, causal loop diagrams were designed in collaboration with thematic experts and the technical workgroup for this study for all themes considered relevant. This resulted in a description of the feedback mechanisms and state variables for all themes and the system as a whole. This graphical representation of the "System Flanders" makes the key dynamics of the system explicit, thereby simplifying the communication between experts with a different background, particularly concerning the interdisciplinary integration. In addition, these system diagrams serve as qualitative description for the scientific aspects of the design of a system dynamics model. The design of qualitative system diagrams is not an easy exercise. Nevertheless the diagrams are a useful contribution to the discussions related to sustainable development and support the assessment of the model fit of models in a system dynamics framework.

A generic fiche with 24 criteria to assess thematic models was subsequently developed, using a template for model categorization used by the European Environment Agency and the design criteria for system dynamics models. The next step consisted of a broad inventory of the established models within Flanders and other regions for the selected themes. The following 16 models were selected: the demographic and macroeconomic model HERMES of the Federal Planning Bureau, the LARCH ecological model, the hydro-ecological process model Pattern-Lite, the RuimteModel Flanders, for the theme Energy the models TIMES and Saver-Leap, for Agriculture the models SELES and emission model Arc-Nemo, for Mobility the Atlas-Transport model, the new water quality model which is being developed for the Flemish Environment Agency, for air quality the models VLOPS, BELEUROS and AURORA, the Milieukostenmodel Air and Climate, and finally a system dynamics model for the use of material resources and waste management in Flanders. The model fit of all selected models was assessed by assigning a score for each criterion, based on the available documentation and estimates by model users. Weights were given to all the criteria which were then applied in a multi-criteria analysis to obtain a general model fit evaluation for all models. A more in-depth discussion of the model fit for a selection of the models is included in this report.

A number of provisional conclusions can be drawn from these results with respect to the model instruments available in Flanders and other regions.

- A large number of thematic models are less based on dynamic modelling of processes, but more using databases pertaining to a reference state of the system, using exogenous, driving variables to include dynamics. Sometimes, a projection from the initial state to a future year is calculated without knowledge of the intermediate states of the system. For example, this is the case for the themes economics and energy. As a result intermediate interruption of the model to exchange data with other models requires substantial adaptations to the model itself and model software. Previous experiences with the integration of models with a different thematic focus or modelling paradigm teaches us that these problems can be solved, but require serious effort.

- The computing time and software platform used for a number of models are other obstacles, but these problems are less essential and can be circumvented potentially by means of empirical modelling. This means that the original model is replaced by statistical relationships between the in- and outgoing model variables, being at the cost of the flexibility and transparency of the model.
- The dependency of some models on substantive reference data for a base year is a more difficult problem. The validity of these data and the corresponding parameter settings for the mid- and long-term (40 years or more) should be examined prior to deciding on the application in a particular model.
- Together, the qualitative system description which is now available, the model assessment procedure, and tentative selection of thematic models form a good starting point for the design of a quantitative system dynamics model which can capture the key dynamics of the integrated "System Flanders" (step 2 from the 4-step methodology) accompanied by in-depth thematic analysis where necessary (step 3).
- The application of generic model assessment criteria to a broad, representative selection of thematic models demonstrates that these criteria are sufficiently transparent and flexible to be used in the 4-step methodology. The criteria can be refined when necessary or the weights adapted.
- The evaluation pointed out the weak and strong characteristics of the models in terms of the model fit. This information can be used to compare models or evaluate the usefulness of specific model combinations for application in the 4-step methodology, and to identify the model aspects which can lead to problems. This allows for model redesign or reconsideration of model choices if necessary.
- Depending on the model these adaptations include the (dis)aggregation of model results, the application of generic functions to extrapolate reference data, empirical modelling to reduce the computing time, and the substitution of internal model parameters by functions which can more easily be controlled by other models or vice versa.