480021 - MMSS - Fundamentals of Mathematical and Systemic Sustainability Modelling

Coordinating unit: 250 - ETSECCPB - Barcelona School of Civil Engineering
Teaching unit: 724 - MMT - Department of Heat Engines
Academic year: 2019
Degree: MASTER'S DEGREE IN SUSTAINABILITY SCIENCE AND TECHNOLOGY (Syllabus 2013). (Teaching unit Compulsory)
ECTS credits: 5  
Teaching languages: English

Teaching staff
Coordinator: MARTI ROSAS CASALS

Degree competences to which the subject contributes

Basic:
CB9. That students can communicate their conclusions-and the knowledge and rationale underpinning these, to specialist and non-specialist audiences clearly and unambiguously.

Specific:
2. The ability to apply, critically and effectively, conceptual frameworks, data collection and processing techniques, applied statistics, mathematical modelling, systems analysis, geographic information systems, information and communication technologies and industrial ecology to meeting the challenges of sustainability and sustainable development.
3. The ability to apply, critically analyse results and assess valorisation theories, approaches and methods in the fields of food and rural development and agricultural, water, energy, building construction, transport and spatial engineering.
CE03. The ability to critically analyse theories and perspectives on the traits and properties of the geosphere and biosphere that facilitate and frame the development of socio-environmental systems, as well as the main challenges posed by climate change.

Generical:
1. Develop and / or implement innovative ideas in a research context by identifying and formulating hypotheses and by submitting to prove objectivity, consistency and viability.

Transversal:
4. FOREIGN LANGUAGE: Achieving a level of spoken and written proficiency in a foreign language, preferably English, that meets the needs of the profession and the labour market.
5. EFFECTIVE USE OF INFORMATION RESOURCES: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.
Learning objectives of the subject

At the end of the course, each student should be able to:

Understand the systemic dimension of the sustainability concept, the characteristics and properties that define its time-dependent dynamics, as well as some of the subtleties that enhance and constrain the relations among the many actors present in a socio-ecological system.

Efficiently apply mathematical and statistical techniques and tools to analyse and tackle with some of the sustainability challenges.

Critically integrate and analyse results coming from the application of mathematical and statistical models in the definition of sustainable solutions and strategies.
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#### Study load

<table>
<thead>
<tr>
<th>Study load</th>
<th>Hours large group:</th>
<th>Hours medium group:</th>
<th>Hours small group:</th>
<th>Guided activities:</th>
<th>Self study:</th>
</tr>
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<tbody>
<tr>
<td><strong>Total learning time:</strong> 125h</td>
<td>37h 30m</td>
<td>0h</td>
<td>0h</td>
<td>7h 30m</td>
<td>80h</td>
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1. INTRODUCTION TO SYSTEMIC

Degree competences to which the content contributes:

Description:
Systemics can be considered a new name for inquiries related to systems theory and systems science. It is defined as an emerging field of science that studies holistic systems and attempts to develop mathematical software frameworks, engineering, and philosophy in which physical, mental, cognitive, social and metaphysical systems can be studied.

Related activities:
A1

Specific objectives:

2. COMPLEXITY AND SUSTAINABILITY

Degree competences to which the content contributes:

Description:
Complexity arises when we observe reality under a systemic point of view. It is the quality of those systems composed of various elements and therefore it is present in fields such as philosophy, epistemology, physics and biology, sociology, computer science, mathematics, and the sciences of information and communication or ICT. The problems associated with the concept of sustainability are often systemic, holistic and complex.

Related activities:
A2/A3

Specific objectives:

3. INTRODUCTION TO MODELLING

Degree competences to which the content contributes:

Description:
A model (in general and here, mathematical) is a way to express attributes and relationships of a system in a simplified way. It is characterized by containing variables, parameters, entities and quantitative relationships between variables and/or entities. It is used to study behaviours of complex systems in situations difficult to observe in reality.

Specific objectives:

4. EQUATION BASED MODELLING

Degree competences to which the content contributes:
**Description:**
The best known mathematical models are those based on differential and difference equations in order to characterize the dynamic evolution (i.e., in time) of the systems under study. Despite their simplicity, some models show sensitivity to initial conditions, a fact that makes their temporal behaviours chaotic and impossible to predict in the long term.

**Related activities:**
A4/A5

**Specific objectives:**

**5. AGENT BASED MODELLING**

**Degree competences to which the content contributes:**

**Description:**
An agent-based model is a type of computational model that allows the simulation of actions and interactions of autonomous individuals in an environment, and to determine what effects they produce in the whole system. These models simulate the simultaneous operations of multiple entities (agents) in an attempt to recreate and predict the actions of complex phenomena, and that may be emerging from the most basic (micro) to the highest level (macro).

**Related activities:**
A6/A7

**Specific objectives:**
Planning of activities

A1. "DARWIN'S NIGHTMARE" MENTAL AND CONCEPTUAL MAPS

Description:
Create the mental and conceptual maps of the film "Darwin's Nightmare"

Support materials:
- Film (http://www.youtube.com/watch?v=IV7Y9FHcdFk)
- CMapTools (http://ftp.ihmc.us/)

Descriptions of the assignments due and their relation to the assessment:
Mental and conceptual maps in PDF format.

Specific objectives:
- Make a mental and conceptual map.
- Develop the capacity to capture the complexity (actors and relations) of this part of the reality presented in the film.

A2. POWER LAWS AND PARETO DISTRIBUTIONS

Description:
Understand one of the characteristic pattern of complex systems such as fat-tailed distributions, and some of its generating mechanisms.

Support materials:
- Guiding questions.

Descriptions of the assignments due and their relation to the assessment:
Answers to guiding questions in PDF.

Specific objectives:
- Differentiate and characterize fat-tailed distribution using basic statistical analysis (spreadsheet).
- Understand the concept of normalization constant.
- Differentiate probability distributions from allometric correlations.

A3. CORRELATION AND CAUSATION

Description:
Understand how correlations between ecosystem services can be analysed and how they can be considered causal relationships.

Support materials:
- Guiding questions.
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**Descriptions of the assignments due and their relation to the assessment:**
Answers to guiding questions in PDF.

**Specific objectives:**
- Recognize the concept of ecosystem services and ‘ecosystem service bundle’.
- Recognize the difference between trade-off and synergy.
- Present the Pearson coefficient as a particular case of mutual information measure for linear correlations and their extrapolation to nonlinear correlations.

### A4. CAUSAL AND FLOW DIAGRAMS

**Description:**
Transform the conceptual map elaborated in activity A1 (or some of its parts) into a causal diagram first and then into a flow diagram.

**Support materials:**
- Conceptual map from activity A1.
- Guiding questions.

**Descriptions of the assignments due and their relation to the assessment:**
Causal and flow diagram of activity A1.

**Specific objectives:**
- Learn how to transform a conceptual map (or any part thereof) in a causal diagram as the necessary first step in modelling complex systems.

### A5. STABILITY ANALYSIS

**Description:**
(a) Transform the diagrams of activity A4 into a system of differential equations; (b) implement them computationally into NetLogo and (c) analyse its stability.

**Support materials:**
- Causal diagram from activity A5.

**Specific objectives:**
- Develop the capacity of abstraction required to generate a model with minimum equations and implement it computationally.
- Understand and analyse its stability.

### A6. INTRODUCTION TO PROGRAMMING

**Description:**
Follow the NetLogo tutorials on agent based modelling.
Support materials:
- NetLogo (http://ccl.northwestern.edu/netlogo/)
- NetLogo Tutorials (http://ccl.northwestern.edu/netlogo/docs/)
- Scientific articles with ODD protocol.
- Scientific articles without the ODD protocol.
- Guiding questions.

Specific objectives:
- Become familiar with the programming language and the interface of the NetLogo program.

A7. THE ODD PROTOCOL AND ITS ADOPTION IN SCIENCE

Description:
Read scientific articles with and without the ODD protocol. For those without ODD protocol, finish them with the missing parts.

Support materials:
- Scientific articles with ODD protocol.
- Scientific articles without the ODD protocol.
- Guiding questions.

Descriptions of the assignments due and their relation to the assessment:
Answers to guiding questions in PDF.

Specific objectives:
- Recognize the potential and usefulness of the ODD protocol as a communication framework of such models with agents.

Qualification system

EV1: Written test (PE). 35%
EV2: Written test (PE). 35%
EV3: Individual or group coursework (TR). This includes results and reports and their oral presentation. 30%
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Bibliography

Basic:


Complementary:


Others resources: