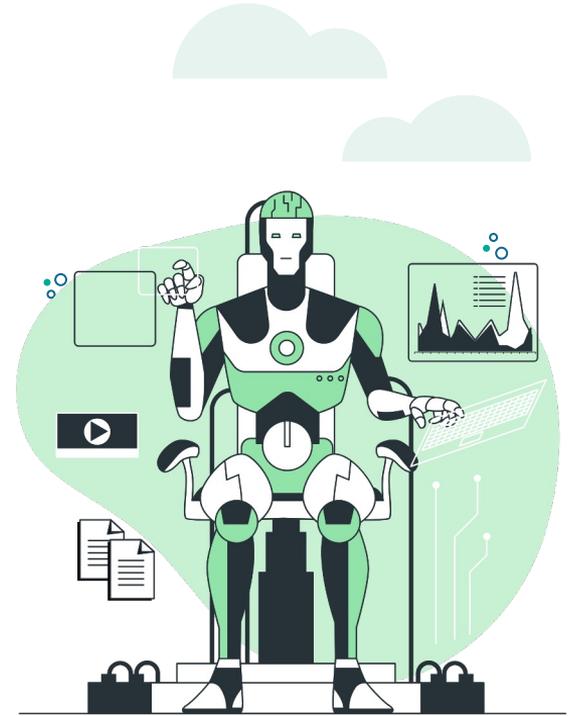


# Model-Driven Engineering for Sustainable Futures Bridging the gap

June Sallou

December 15<sup>th</sup>, 2023  
MDENet France Workshop 2023





**Betty H.C. Cheng**  
**Keynote MODELS 2020**

Model-Driven Engineering for Data-Centric Autonomous Systems

<https://conf.researchr.org/track/models-2020/models-2020-keynotes#betty-hc-cheng>

# My perspective



Univ Rennes – DiverSE  
SE - MDE

Scientific Modelling – Decision Making



TU Delft – SERG  
SE

Sustainable Software – Green AI

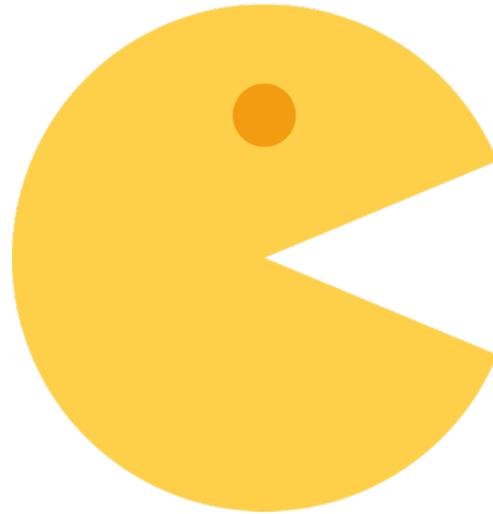


**Software** is eating the world!\*



\*[Marc Andreessen, 2011]

**(AI-based) Software** is eating the world!



# (AI-based) Software is Heating the world!



Energy consumption of ICTs:  
~21% of the global total electricity  
usage by 2030 [A. S. Andrae and T. Edler,  
2015]

Computing for AI training has been  
doubling every 3.4 month since  
2012. [OpenAI, 2018]

# Sustainable (AI-Based) Software



# Open Challenges

 Sustainable (AI-based) Software





# MDE to the rescue: Everything as a model!



*Model: abstraction of an aspect of reality for a given purpose.*

- Software
- AI Model
- Development process
- Sustainability
- Context
- Business Model
- ...

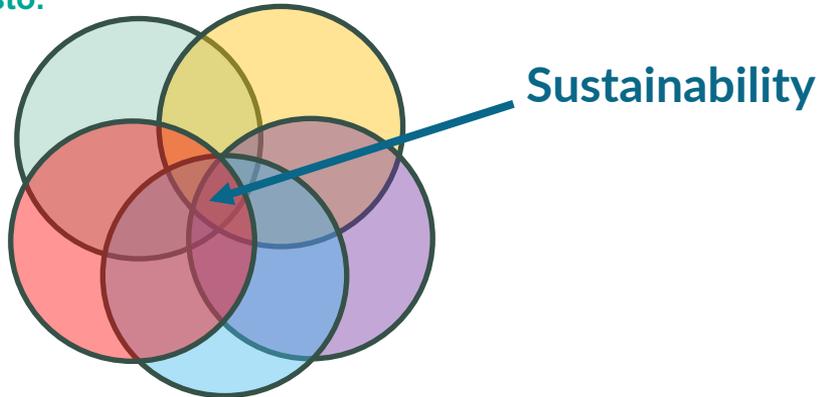


# Complexity

How to encompass sustainability complexity with software complexity?

→ Becker, Christoph, et al. "2015 IEEE/ACM 37th IEEE International Conference on Software Engineering."  
**Sustainability Design and Software: The Karlskrona Manifesto.**

→ « Divide to conquer »  
→ MDE, Scientific Models  
→ Systemic Approach





# Adaptation

Sustainable software takes different shapes according to :

- Purpose
- Execution context
- Application domain
- Business environment
- Step in the life cycle / Time

→ Combination of different models (+data) : MODA Framework.

→ Runtime models, simulation, decision making.

- Becker, Christoph, et al. "2015 IEEE/ACM 37th IEEE International Conference on Software Engineering." **Sustainability Design and Software: The Karlskrona Manifesto.**
- Hilty, L. M., et al. "Rebound effects of progress in information technology." *Poiesis Prax.*, vol. 4, no. 1, 1 Mar. 2006.

## A Hitchhiker's Guide to Model-Driven Engineering for Data-Centric Systems

Benoit Combemale<sup>1</sup>, Jorg Kienzle<sup>2</sup>, Clément Munchachet<sup>3</sup>, Sébastien Aÿ<sup>4</sup>, Daniel Ammer<sup>5</sup>,  
 Mojibeh Bagherzadeh<sup>6</sup>, Edoardo Barot<sup>7</sup>, Nelly Benmoune<sup>8</sup>, Benjamin Boutev<sup>9</sup>, Anne-Michèle Brunet<sup>10</sup>,  
 Gadi Cheloufi<sup>11</sup>, Barry Eick<sup>12</sup>, Thierry François Collet<sup>13</sup>, George Kaprielidis<sup>14</sup>, Ralf Klösch<sup>15</sup>,  
 Jean-Marie Lécuyer<sup>16</sup>, Anne Kretschmer<sup>17</sup>, Sébastien Marnat<sup>18</sup>, Ralf Reussner<sup>19</sup>, Hassan Sakr<sup>20</sup>,  
 Ralf Sauer<sup>21</sup>, Laure Taffet<sup>22</sup>, Sergio Traverso<sup>23</sup>, Eugene Trifunov<sup>24</sup>, Manuel Wimmer<sup>25</sup>

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<sup>23</sup>Univ. Toulouse & Inria, France, sergio.traverso@inria.fr  
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**1. INTRODUCTION**

A broad spectrum of application domains are increasingly making use of heterogeneous and large volumes of data. This brings specific challenges to the way the different sources of Artificial Intelligence (AI) and, in particular, Machine Learning (ML) gather, exploit, the benefits of data in the development, maintenance, evolution, and innovation and management of systems built with model-driven engineering techniques. Applications include critical infrastructure systems in multiple transportation, smart energy management, health monitoring and control, and digital manufacturing. While the combination of data and machine learning have proven to be a powerful application (e.g., a fraud detection system), these systems also bring socio-technical concerns that require attention [2], [3]. Such an integration requires the individual strengths of machine learning as well as their underlying modeling and conceptualization. In support of data-centric and ML-based systems, the integration of heterogeneous models and their evolution in the entire lifecycle of a socio-technical system is a key challenge. While system development within these domains application domains makes use of both models and data, it differs in the types and uses of models and data, and the degree and role of humans in the loop. E.g., ML models are applied to integrate data.

- Combemale, Benoit, et al. "A Hitchhiker's Guide to Model-Driven Engineering for Data-Centric Systems." *IEEE Software*, vol. 38, no. 4, 15 May. 2021



# Accessibility

To ensure sustainable software in practice, we need to provide :

- Developers with the knowledge and/or expertise
- Available tools and methods
- Adapted to specific use cases

→ Abstraction

→ Domain Specific Languages

→ Pang, C., Hindle, A., Adams, B., & Hassan, A. E. (2015). **What Do Programmers Know about Software Energy Consumption?** IEEE Software

→ Wąsowski, Andrzej and Thorsten Berger. **Domain-Specific Languages: Effective Modeling, Automation, and Reuse.** Springer International Publishing, 2023.



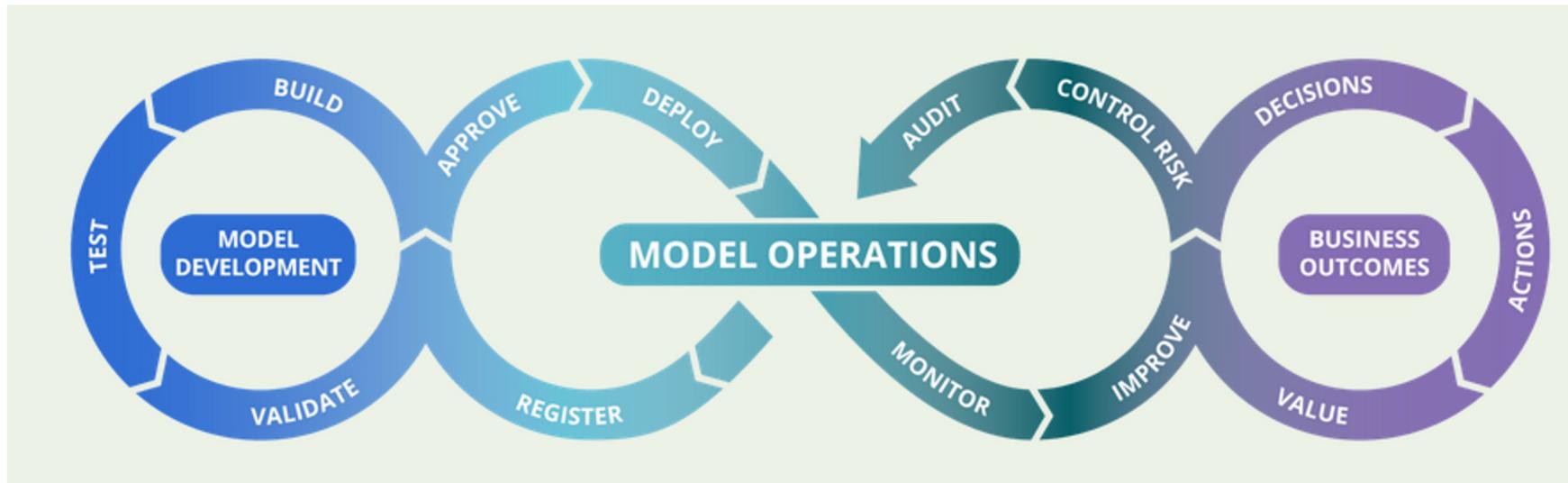
# Integration

How to integrate sustainability as a requirement in software practices?

- Domain Specific Languages
- Requirement engineering

- Kienzle, Jörg, et al. "**Toward model-driven sustainability evaluation.**" Commun. ACM, vol. 63, no. 3, 24 Feb. 2020
- Saputri, Theresia Ratih Dewi and Seok-Won Lee. "**Integrated framework for incorporating sustainability design in software engineering life-cycle: An empirical study.**" Information and Software Technology, vol. 129, 1 Jan. 2021

# ~~DevOps / MLOps~~ → ModelOps\*



# Digital Twins for Sustainability

Digital Twin: *“a virtual representation of an actual system that it is continuously updated with real-time system data throughout its life cycle and, at the same time, allows to interact with and influence the system.”*

→ Bordeleau, Francis, et al. "Systems Modelling and Management." **Towards Model-Driven Digital Twin Engineering: Current Opportunities and Future Challenges**. Springer, 17 Oct. 2020

→ Heithoff, Malte, et al. "2023 IEEE/ACM 7th International Workshop on Green And Sustainable Software (GREENS)." **Digital Twins for Sustainable Software Systems**.

# Digital Twins for Sustainability in Software Development Process

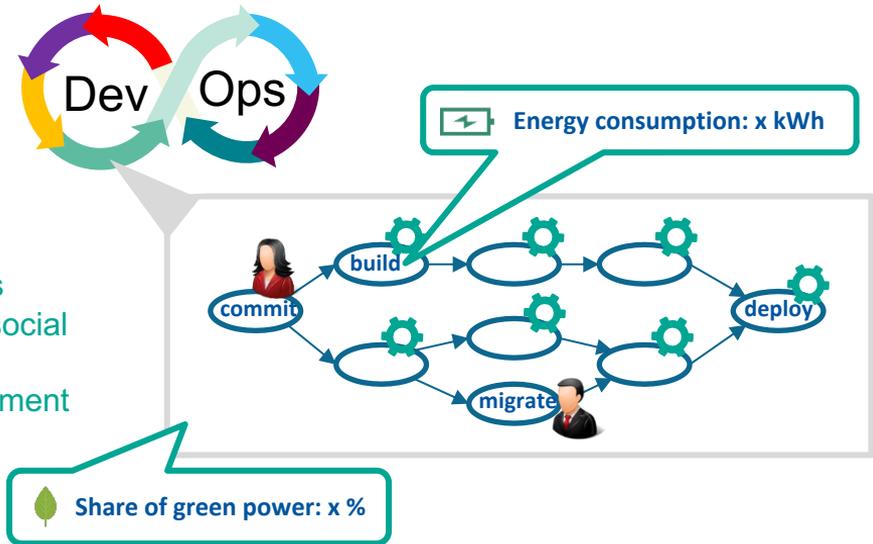


→ Language components and a method to monitor software development processes

→ Collaboration with Dr. Judith Michael

Aims:

- Model development process with BPMN
- Language extension for BPMN
- Metrics for sustainability
- Annotate relevant sustainability metrics to specific process steps
- Extensible for metrics in the areas of economic, ecological and social sustainability
- Evaluated using the development process of a software development project
- GitHub Projects & Actions





CONTEXT



CHALLENGES



VISION



TEACHING



PLANS

# Multi- & Transdisciplinary

**MDE**



**Sustainability**



# THANKS!

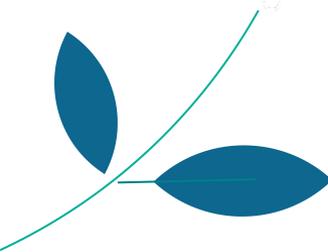


Do you have any questions?

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[@junesallou](https://twitter.com/junesallou)



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