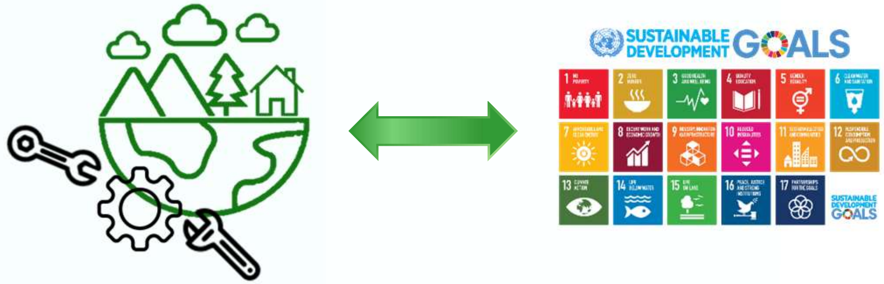

Enabling Informed Sustainability Decisions: Sustainability Assessment in Iterative System Modeling

16th Int. Workshop on Models and Evolution (ME’23)

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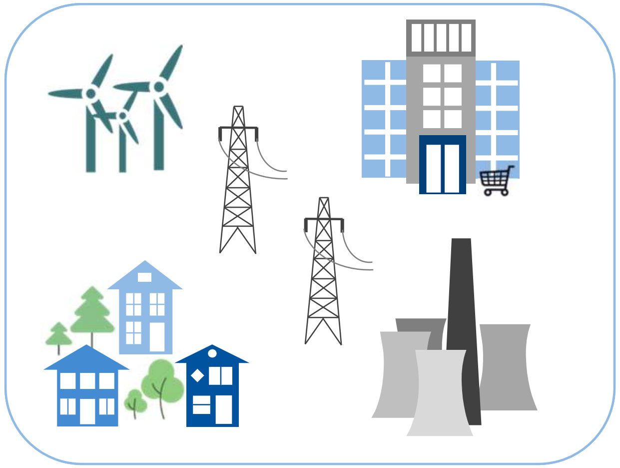
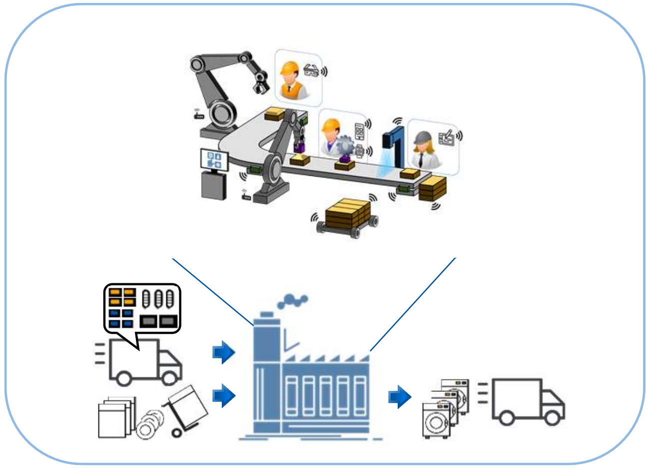
Motivation

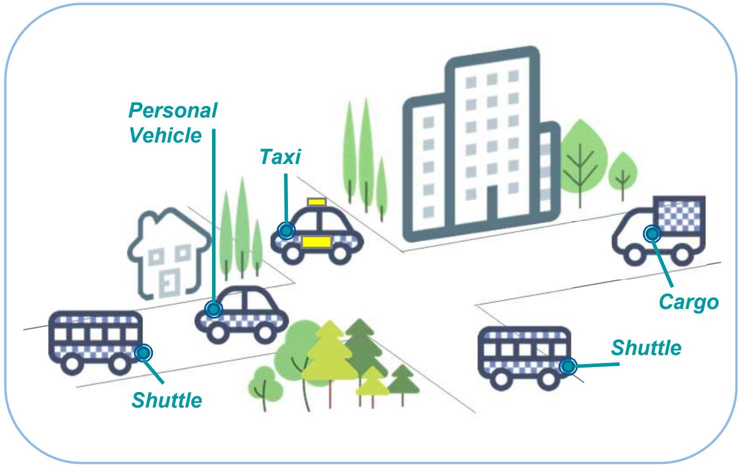
- Planning, creating, evolving systems
  - Cyber-physical systems
  - Technical systems
  - Socio-technical systems
- Assess their impact
  - Social, economic, environmental
  - Lack connections to SDGs



Energy Systems



Production Systems



Transport Systems

Towards more Sustainable Development Decisions

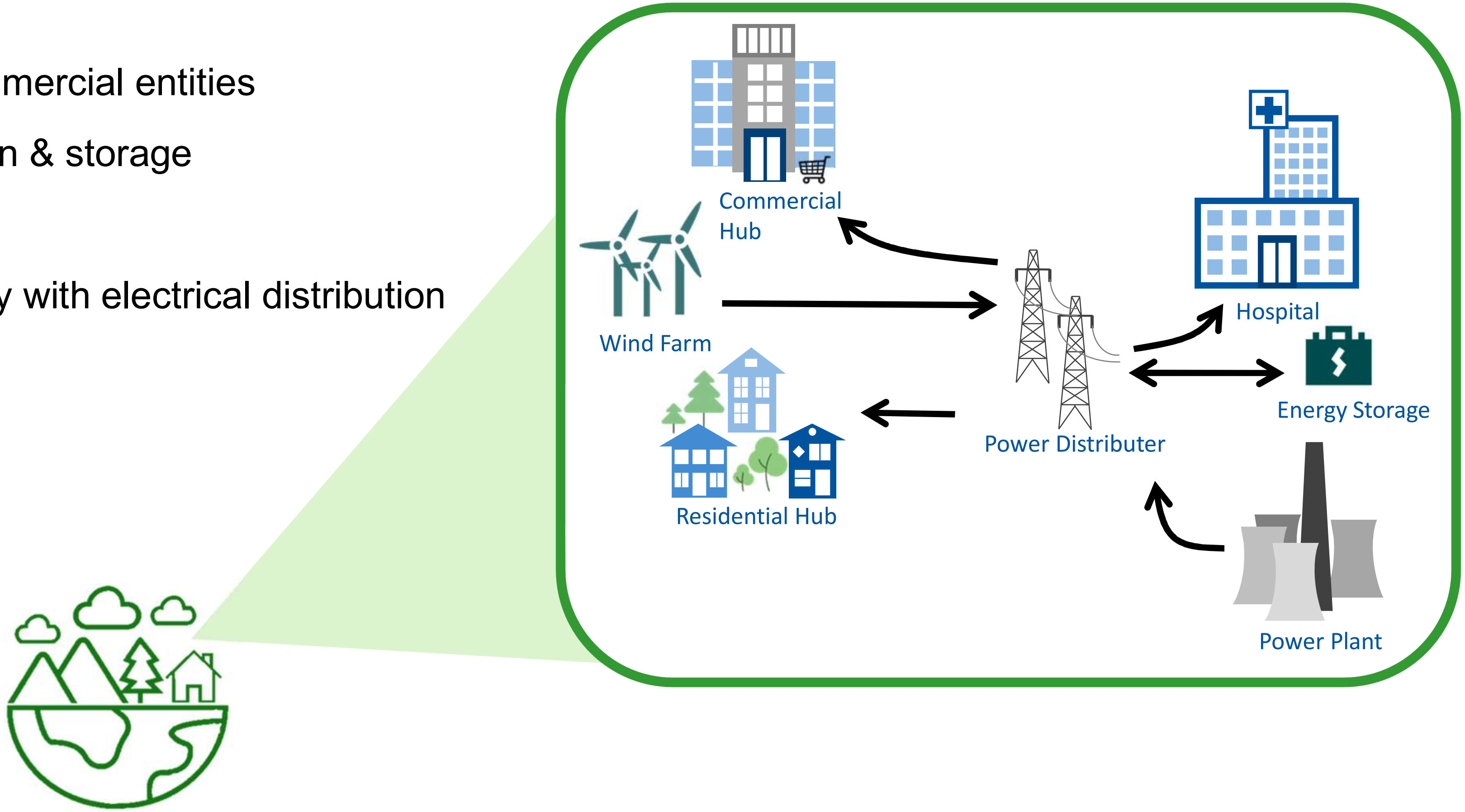
Research Question

How to enable system developers to iteratively evolve a system in a sustainable way?

- Lead software and system engineers towards sustainable development decisions
  - *Experimentation* kit
  - Model the system under development
  - Sustainability assessment
  - Inform developers about *assessment results* for currently modeled system
- Extend models with sustainability indicators
  - Language composition: Architecture Description Language and Sustainability DSL
- Extend sustainability DSL with domain-specific modeling libraries
  - Domain-specific indicators (e.g., LCSA indicators)

Example: Citizen Energy Communities

- Citizens and small commercial entities
- Local energy generation & storage
- Local energy trading
- Citizens interact directly with electrical distribution system

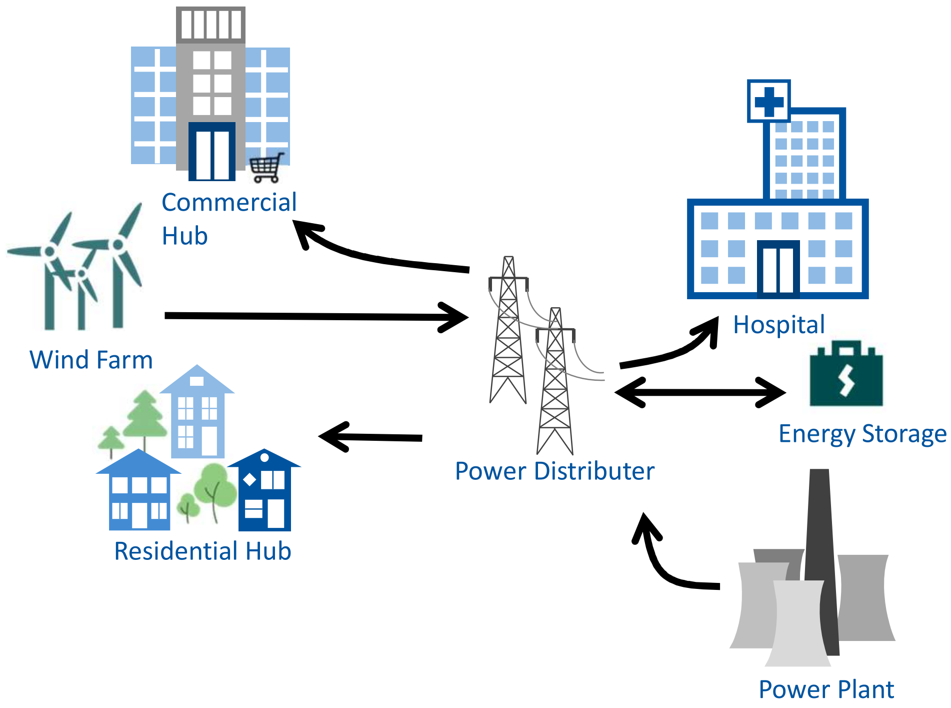


Example: Citizen Energy Communities

- Architecture Description Language
  - MontiArc using MontiCore language workbench

MA

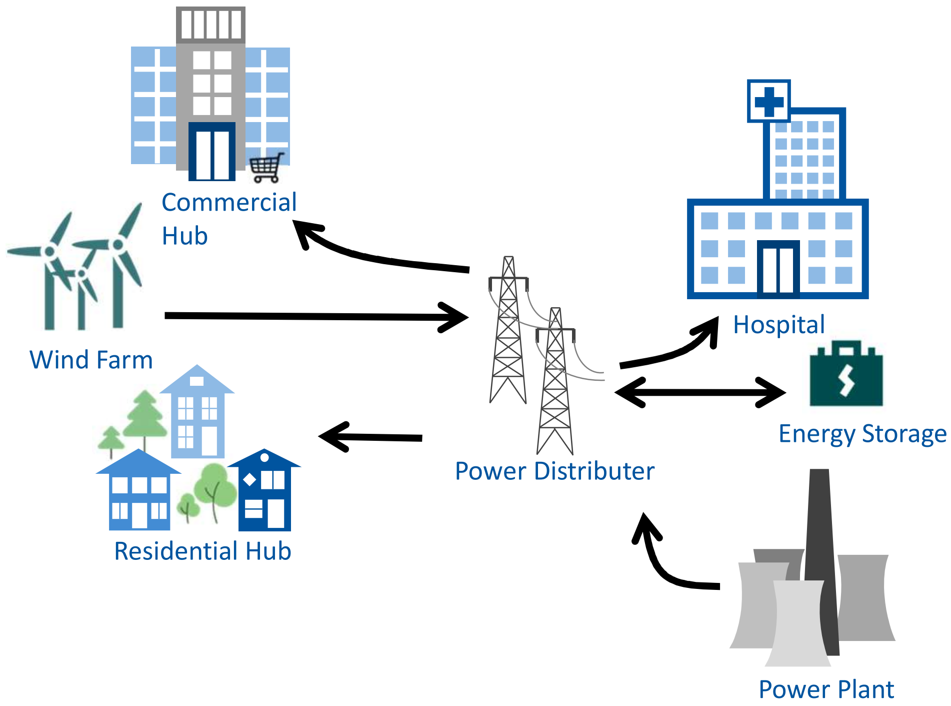
```
component CitizenEnergyCommunity{
  … port …

  component Hospital hospital;
  component CommercialHub comHub;
  component ResidentialHub resHub;
  component WindFarm windfarm;
  component PowerDistributor distrib;
  component EnergyStorage storage;
  component CoalPowerplant powerplant;




}
```



Example: Citizen Energy Communities

- Architecture Description Language
  - Sustainability DSL

```
component CitizenEnergyCommunity{                    MA
  … port …

  component Hospital hospital;
  component CommercialHub comHub;
  component ResidentialHub resHub;
  component WindFarm windfarm;
  component PowerDistributor distrib;
  component EnergyStorage storage;
  component CoalPowerplant powerplant;

  satisfy sustainability{
    sdg: [7,11,13]…
  }
}
```

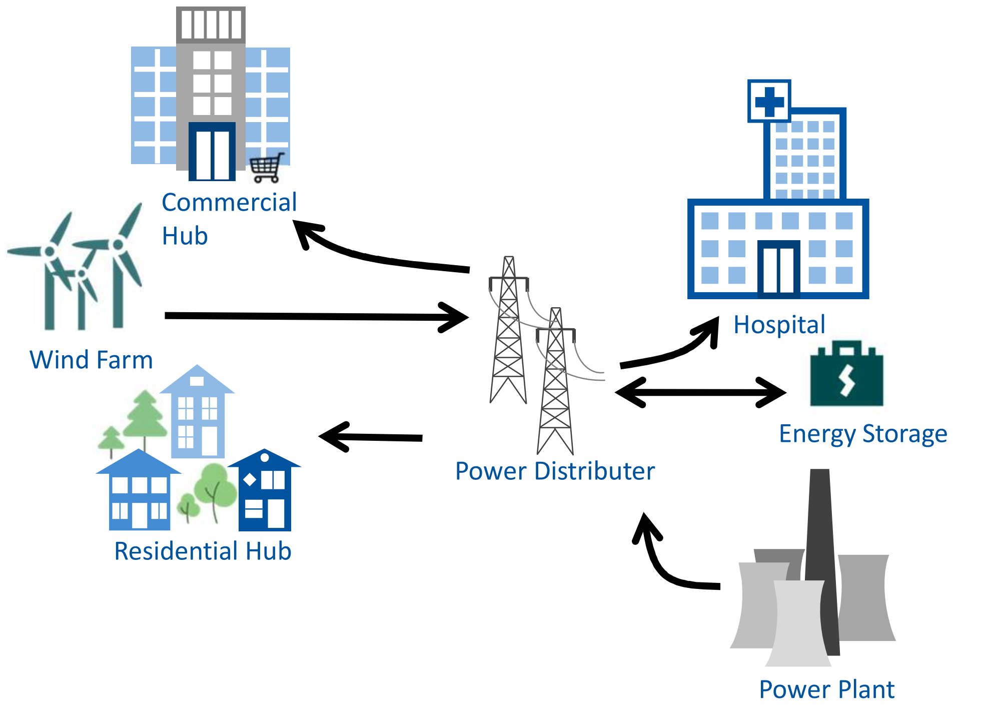


Example: Citizen Energy Communities

- Architecture Description Language
  - Sustainability DSL

MA

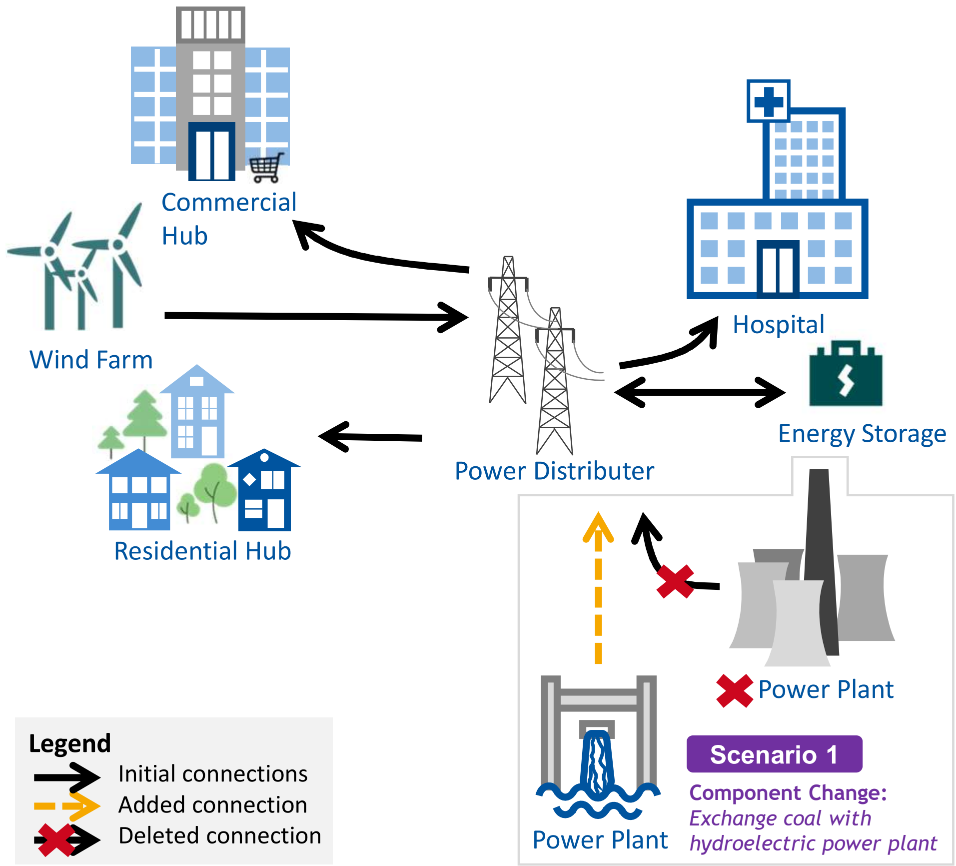
```
component CoalPowerplant{
  port
    out ElectricalEnergy ee;

  sustainability{
    type: energy, structure, process;
    indicators{
      consumption: coal;
      co2Emission: 950 gCO2/kWh;
      landscapeUsage: 1km^2;
      ...
    }
  }
}
```



Evolution Scenario 1 | Component Change

- Black-box architecture is unchanged

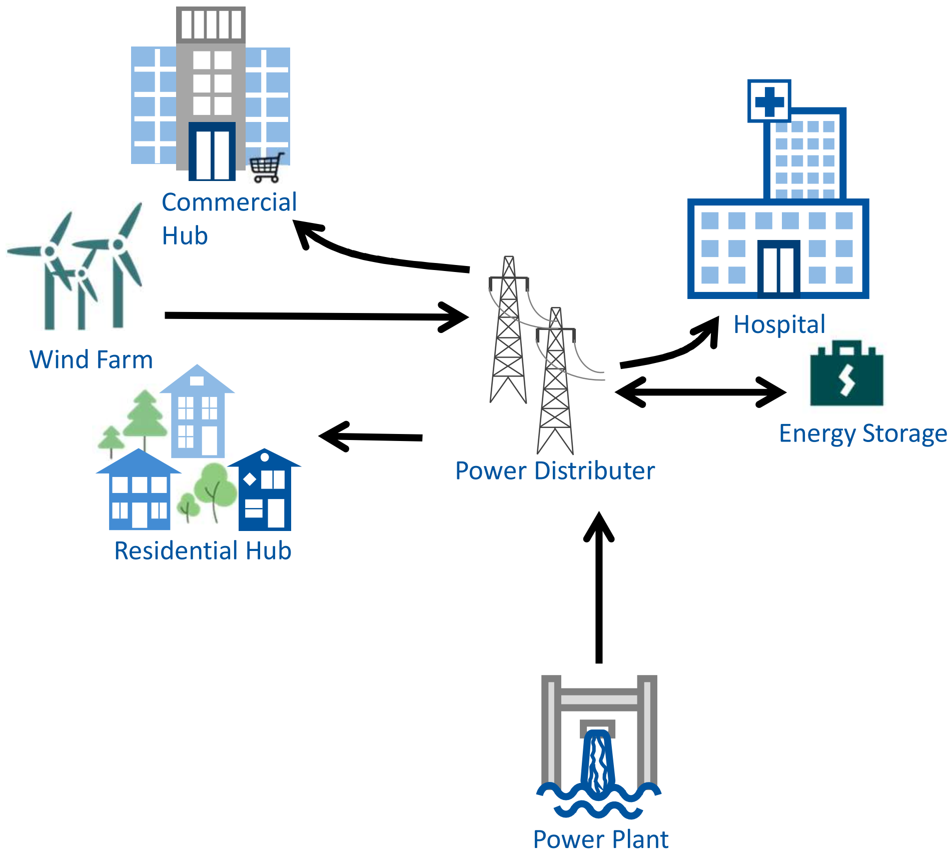
```
component HydroPowerplant{                          MA
  port
    out ElectricalEnergy ee;

  sustainability{
    type: energy, structure, process;
    indicators{
      consumption: renewable, hydro;
      co2Emission: 24 gCO2/kWh;
      landscapeUsage: 2km^2;
      ...
    }
  }
}
```



Evolution Scenario 1 | Component Change

- *Sustainability Assessment*
  - assessed by experts or
  - passed on to assessment systems
    - domain-specific systems
    - *Sustainability Evaluation Experience* R (SEER) [KMC+20]

- Example
  - Reduced the power plant's CO_2 emissions by over 95%
  - Slightly positive effects for SDGs 7, 11, and 13

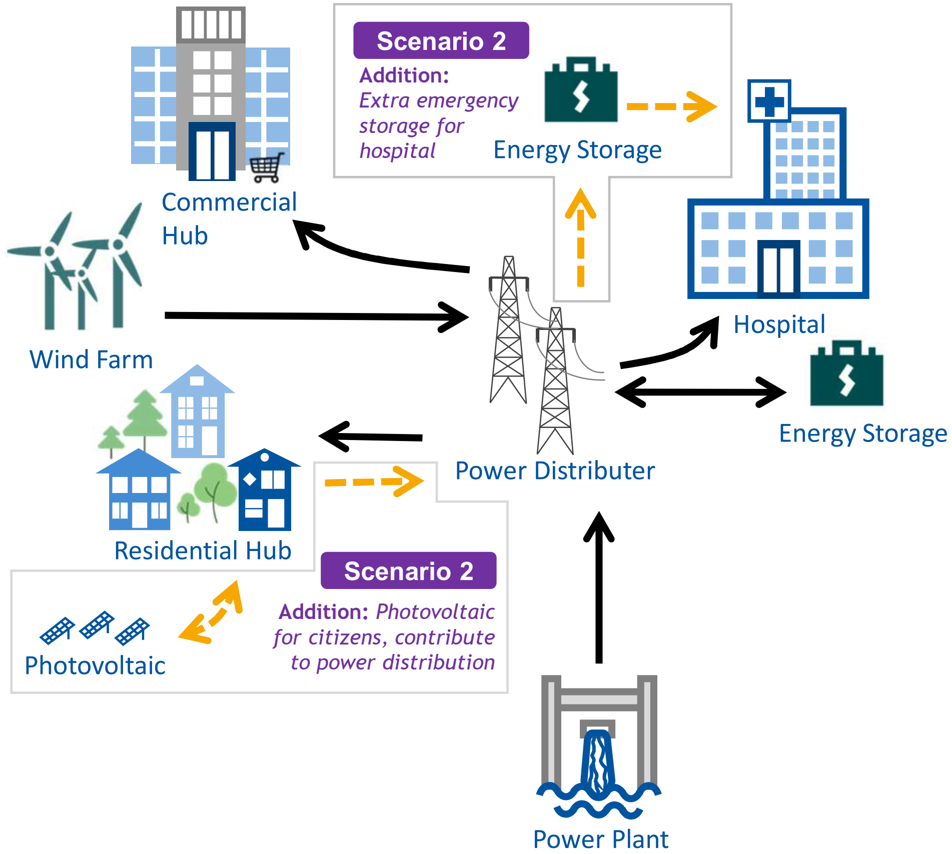


[KMC+20] J. Kienzle, G. Mussbacher, B. Combemale, L. Bastin, N. Bencomo, J.-M. Bruel, C. Becker, S. Betz, R. Chitchyan, B.H.C. Cheng, S. Klingert, R.F. Paige, B. Penzenstadler, N. Seyff, E. Syriani, C.C. Venters: Toward model-driven sustainability evaluation. Commun. ACM 63, 3, 2020.

Evolution

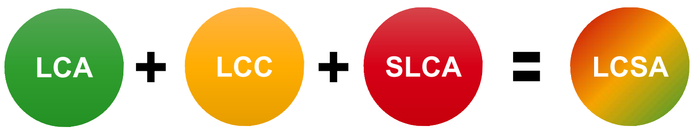
- Scenario 2
  - Addition of emergency energy storage
  - Addition of photovoltaic units to residential hubs

- Assessment
  - Better results



Sustainability Assessment

- *Lifecycle Sustainability Assessment* (LCSA)
  - LCA = Environmental Life Cycle Assessment
  - LCC = LCA-type Life Cycle Costing
  - SLCA = Social Life Cycle Assessment



- Lack a *connection* between *LCSA indicators* and *SDG goals* and more concrete target
  - As of 2022, 14 SDG goals have not yet been assigned LCSA indicators

- *(Some) Challenges*
  - Tool supported but also *manual effort*
  - Data *availability*
  - Some approaches in practice consider *only two* of the *three main sustainability aspects*
  - Lack *interconnectedness* among the three areas
  - Do not follow *cause-effect chains*
  - System *boundaries* unclear/ inconsistent
  - Non-transparent *weighting of results*
  - *Lack of agreement* in the international community on *social targets* to achieve for many social indicators
  - …

Sources:
- *M. Finkbeiner, E.M. Schau, A. Lehmann, M. Traverso: Towards Life Cycle Sustainability Assessment. Sustainability, 2010.*
- *S. Valdivia, J. G. Backes, M. Traverso, G. Sonnemann, S. Cucurachi, J. B. Guinée, T. Schaubroeck, M. Finkbeiner, N. Leroy-Parmentier, C. Ugaya, C. Peña, A. Zamagni, A. Inaba, M. Amaral, M. Berger, J. Dvarioniene, T. Vakhitova, C. Benoit-Norris, M. Prox, R. Foolmaun, M. Goedkoop: Principles for the application of life cycle sustainability assessment," The International Journal of Life Cycle Assessment, vol. 26, no. 9, 2021.*
- *J. Martínez-Blanco, A. Lehmann, P. Muñoz, A. Antón, M. Traverso, J. Rieradevall, M. Finkbeiner: Application challenges for the social Life Cycle Assessment of fertilizers within life cycle sustainability assessment. Journal of Cleaner Production, vol 69, 2014.*

Roadmap

1. Refining and extending Sustainability DSL **for other domains**
2. Combine with **digital twins**
3. Further research **interlinkages** between SDGs
4. Extend with **model-processing tooling** for automated sustainability assessments
5. Extend approach for **other languages** beside ADLs

Summary and Discussion

Enabling Informed Sustainability Decisions: Sustainability Assessment in Iterative System Modeling

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***Abstract*—When planning, creating, and evolving systems throughout their lifecycle, it is essential to assess their impact on our world. Despite this pressing need, existing structured methods for systematically assessing social, economic, and environmental impacts are not related to targets of the United Nations' sustainable development goals. Moreover, existing Architecture Description Languages (ADLs) lack concepts and tooling for sustainability assessment. Our aim is to allow modeling systems, their sustainability properties, and sustainability questions in a structured manner for a wide domain. This paper proposes the engineering and design of a domain-specific language for sustainability assessment embedded into ADLs and showcases its use for evaluating a citizen energy community system as a case study. We discuss possibilities on how to use such models in their further processing and explore challenges in technical realization. This initial step towards standardizing the sustainability assessments of modeled systems throughout the development is both comprehensive and formal so that developers can make informed, sustainable decisions based on consequence assessments upfront.**

***Index Terms*—Systems Engineering, Domain-Specific Languages, Model-Driven Engineering, Sustainable Development Goals, Life-Cycle Sustainability Assessment, Architecture Description Language, Energy Planning**

I. INTRODUCTION

Motivation. When developing and evolving systems, technologies, and processes over a longer period of time sustainability plays a significant role in each decision point of developers. Such systems include the production domain, Internet of Things (IoT), Cyber-Physical System (CPS), or pure software systems. Development decisions may lead to negative influences on different sustainability goals [1] in the areas of social, economic, and environmental sustainability [2].

Research Question. We tackle the main research question of how to enable system developers to iteratively evolve a system throughout its life cycle in a sustainable way.

Contribution. To make these informed decisions, we suggest a model-based approach that incorporates sustainability descriptions in Architecture Description Language (ADL) models. This paper explores and introduces an approach to combine sustainability assessment defined in a Domain-Specific Language (DSL) with ADL models throughout an iterative development process. The approach supports decision-making through a system's evolution and leads to the implementation of sustainable systems. As a running example, we show two development scenarios in an energy planning case study for a citizen energy community.

Structure. We provide foundations, use a running example to introduce the methodology for sustainable system development, and conclude with a roadmap for implementing DSLs and assessing sustainability.

II. PRELIMENARIES

Architecture Description Languages. For modeling systems, ADLs [3] offer great possibilities for iterative development. Most ADLs follow the component-connector approach, where a system architecture is defined by its components/parts and their connectors/ports. Often, additional (behavior) description possibilities are offered for atomic components through language compositions, e.g., state charts [4]. Components define their communication interface through input and output ports.

*Corresponding author.

Facilitate the *sustainability decision-making*
throughout the *lifecycle of systems*
by embedding *sustainability descriptions* in *ADL models*

…more in the paper

- (Some) Questions
  - What additional methods are needed to support evolution?
  - How to increase the SDG knowledge of technological experts?
  - How to increase automation in the assessment?

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