Center for Sustainable ICT – CESICT

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Abstract

Center for Sustainable ICT - CESICT will promote interdisciplinary and intersectoral approaches to ensure that the development and evolution of ICT solutions is done in a sustainable manner. The center will in combination with our national and international partners play an important role in the achievement of a climate-neutral sustainable economy as set out by the EU Commission and the Norwegian Climate Plan. To achieve this goal, there is an urgent need for the ongoing digitalization to both contribute to sustainability in other fields, and at the same time be sustainable in itself.

Although there is a focus on environmental sustainability in the Climate Plans, this must be balanced with social, individual, economic, and technical sustainability as we develop new, innovative, holistic methods, technologies and solutions to support a sustainable digitalization of society.

We present in this research project exhibition the focus and the main goals of the center, current results and plans for future activity and national and international collaboration.

Keywords

ISE for sustainability, Sustainable ICT, Sustainability by design

1. Project objectives and tangible outputs

The Informatics and Electrical Engineering (IE) faculty at the Norwegian University of Science and Technology (NTNU) have taken the initiative establish a new Center for sustainable Information and Communication Technology (CESICT[2]). It will promote interdisciplinary and intersectoral approaches to ensure that the development and evolution of ICT-solutions is done in a sustainable manner. The center will act as an NTNU-coordinated network of activities for research institutions, industries, and the public sector, and will be hosted by the IE-faculty and administrated by NTNU Digital, which are NTNUs cross-disciplinary research program in the area of digitalization. The center has the following vision, mission and main goal:

- **Vision:** Knowledge leading to the development and evolution of sustainable ICT solutions for sustainable development
- **Mission:** Mobilize multidisciplinary expertise collaborating to guide digitalization of society in a sustainable direction
- **Goal:** Develop innovative, holistic methods, technologies and solutions to support a sustainable digitalization of society, where the research-based knowledge developed is to benefit both nationally and internationally

RPE@CAiSE'23: Research Projects Exhibition at the International Conference on Advanced Information Systems Engineering, June 12--16, 2023, Zaragoza, Spain
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[2] https://www.ntnu.edu/web/cesict/center-for-sustainable-ict

The primary objective of the centre is to establish a new paradigm in ICT research. The centre will rethink software processes to incorporate sustainability aspects on all levels. The secondary objectives are to:

O1. Establish a sound theoretical base to include environmental and social values in the information system and software processes
O2. Establish an open science research platform for coordinated longitudinal empirical studies on ICT development and evolution in different domains

The success of the center will be measured by supporting existing initiatives and contributing to the launch of new large-scale research and development projects in the area, with a main acquisition goal of achieving the status of SFI (Center for Research Based Innovation) in the next round of calls, alternatively an FND (Forskningssenter for næringsrettet digitalisering) as described in the Norwegian Digital21 Strategy and the Declaration from Hurdal from the current Norwegian Government. The center should also be involved in proposals to the next call for SFF (Center of Excellence in Research).

As we all are aware of, climate change and its consequences will provide enormous challenges to society over the next decades [7,12]. Society needs to address these challenges, both by mitigating the changes and by adapting to them. At the same time, we need to assure that the resulting society is both economically viable, technical feasible and secure and socially desirable.

ICT plays an important role in assuring both environmental, economic, and social sustainability. The need for the ICT field to address sustainability has been acknowledged for some time in areas such as Information systems [20], HCI, and software engineering, as witnessed for instance in the Karlskrona manifesto [1]. The impact of information technology can be seen as both direct and indirect effects of the software and hardware developed and deployed [10]. Direct effects such as energy consumption are what Hilty et al. [10] denote first-order effects, which are substantial according to Freitag et al. [9]. Second-order effects include the consequences of processes being changed (e.g., in transportation or production) by the application of ICT. Third-order effects are seen as long- and medium-term change in behavior, such as change in consumption patterns, and change in economic structures. These effects come with a considerable number of possible challenges. For instance, increased effectiveness of an algorithm as a central part of a new app might on the one hand lead to less energy use but might also lead to extensive use of a system and the first-order effect of requiring more server capacity and using more electric power in one or more physical locations. The need for more transportation of goods might be a second-order effect of extensive use of a hugely popular app connected to a web shop. The change in purchasing habits of a large amount of people can lead to the third-order effect of physical shops in city centers closing down unless they are able to combine the physical offering with a digital one. Those responsible for creating/acquiring/adapting the ICT solutions have to be aware of such consequences to be able to take well-informed decisions and give good advice e.g., to clients and regulators. From being an expert comes responsibility for awareness, information seeking, collaboration, and concern for the common and long-term good.

The information system development process including the software development process is the most important enabler for a future where trustworthy software impacts the quality of people's lives in society. Information systems engineering and software engineering holds the scientific theory for the design, implementation and maintenance of software systems in an organizational setting.

Today, processes for designing and evaluating software are based on direct functionality, cost and value for industry, without sufficient focus on the wider societal and environmental impact of software, which is changing the way software is to be developed and evolved. A shift towards a focus on sustainable development constitute a major change in perspective.

One of the core competence areas of professionals involved in the development of ICT is the identification and representation of information system and software requirements and turning these into operational software. For contemporary ICT-solutions, sustainability can be considered a key non-functional cross-cutting requirement. Becker et al. [2] have developed a framework structuring the effects of ICT-systems into five dimensions. Three of them are used in several sustainability models and originate in [6]: The economic, the environmental, and the social dimensions. To this, Becker and

colleagues add the individual and the technical dimension, and these five dimensions are often depicted as a pentagon as seen in Figure 1 below.

For each of the five dimensions, this pentagon model distinguishes between immediate, enabling and structural effects, corresponding to the first-, second- and third-order effects outlined in [10]. The pentagon model has been used in the development of a model for sustainability evaluation of ICT projects [17] where it is denoted as 'sustainability analysis diagram'. In [12] we used the framework to understand the aspects of sustainability identified in case studies in student courses. Other frameworks in use combine the personal and social levels into one, thus having four dimensions [5].

The model depicts the ICT-systems in the middle, discussing this from a software engineering point of view. When you look at the development and evolution of ICT from an information system point of view the solutions you make e.g., in changing the (work) processes is also including some enabling effects per se, but for simplicity we keep the original figure.

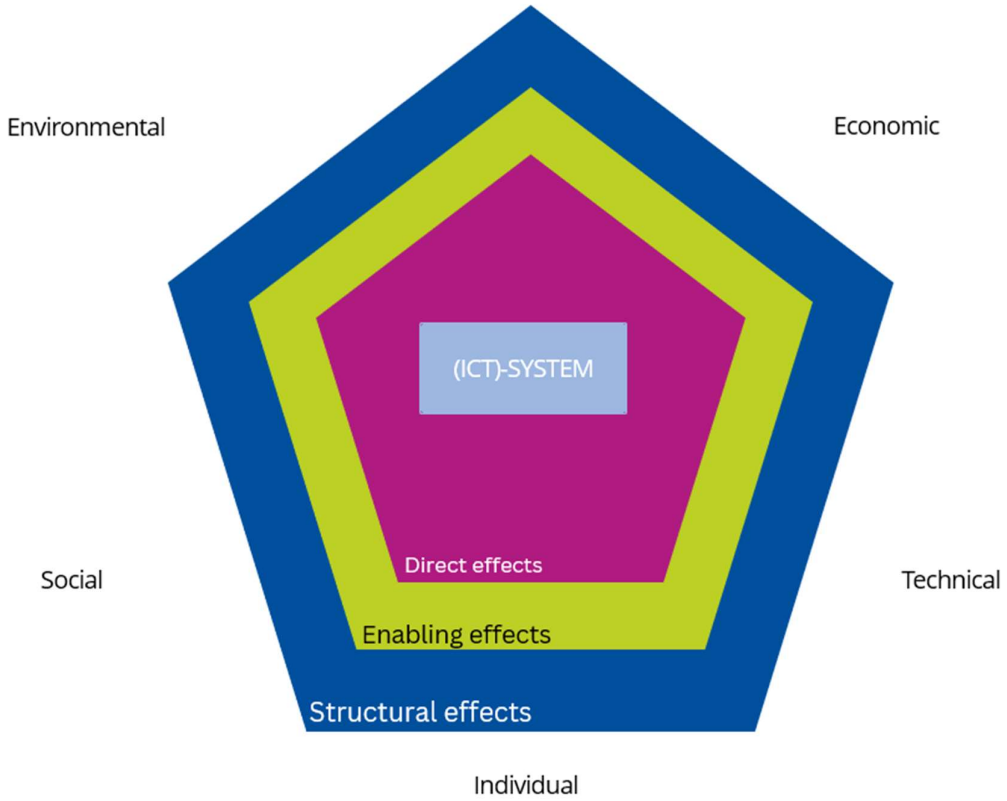

Figure 1: Sustainability analysis diagram (based on [2])

The five dimensions can be described in more detail in the following way: [2]

- *The environmental dimension* covers the use and stewardship of natural resources. It includes questions ranging from immediate waste production and physical resource and energy consumption to the balance of local ecosystems and climate change concerns.
- *The technical dimension* covers the ability to maintain and evolve artificial systems (such as software) over time. It refers to maintenance and evolution, resilience, and the ease of system transitions. According to [8,11] on average only between 20-25 % of the work used on ICT in organizations is used on developing new functionality in new or existing software systems, whereas the rest of the time is used to keep the existing systems operational. The technical dimension of sustainability has to be seen in the light of that there is an external pressure to

change the ICT-systems, i.e., one must be able to evolve existing systems for them to not become obsolete [3].

- *The individual dimension* covers individual freedom and agency (the ability to act in an environment), human dignity, and fulfillment. It includes individuals' ability to thrive, exercise their rights, and develop freely.
- *The social dimension* covers *relationships* between individuals and groups. For example, it covers the structures of mutual trust and communication in a social system and the balance between conflicting interests.
- *The economic dimension* covers financial aspects and economic business value. It includes capital growth and liquidity, investment questions, and financial operations.

These dimensions are often interlinked, so that an effect in one area can have positive or negative effect on another.

Some areas that need to be taken into account in the future of ICT development and evolution are:

- There is a limitation of available human resources to develop, operate and evolve the information systems and software base. How to manage this in a way not overexploiting the available resources, with depleting the IT-resources in developing countries to fill the needs of the western world?
- How to ensure that sustainability aspects are taken into account in functionality decision in (agile) software development, when a large part of society is potential stakeholders?
- Whereas the focus in software engineering has been shorter and shorter release cycles with agile development, devops, and continuous deployment, it has recently been recognized that one need to also support a slower, more traditional mode for certain long-term functionality such as security and safety. Is this so-called bi-modal view of software development possible to extend into also taking all aspects of sustainability on the structural level into account?
- How to develop and maintain and operationalize sustainability requirements? This includes the next point.
- How to support LCA (life-cycle analysis) for software products and systems, coordinated with LCA analysis of physical products (that more and more include software as part of the total product)? In particular, it is a challenge when basing solution on data and services in loosely coupled digital ecosystems, where numbers from LCA of the provided services such as cloud providers are also to be taken into account.
- How to capture necessary data for following up the adherence to sustainability goals in a sustainable and privacy-preserving manner?
- Understand and address the gender imbalance from the point of view of technology to identify and establish those aspects that must be considered to achieve a more inclusive and fair technology.
- Understand and address citizens' engagement in sustainable regeneration processes to establish and apply a set of measures to empower them for sustainable practices in and by new technologies.
- Understand and address geographical differences that affect egalitarian and inclusive processes in and by technology to propose new ways of understanding and collaboration that remove these barriers.
- Additional ethical issue, e.g., how algorithms and AI influence human activity, and the undemocratic power of large technology providers.
- Negative structural effects are hard to foresee and ensure to avoid on individual projects. How to inform and support policy makers to develop and enforce policies that ensure sustainability on the structural level?

This is not an exhaustive list.

2. The Relevance of the Project to the Topics of the International Conference on Advanced Information Systems Engineering (CAiSE)

Information Systems Engineering is occupied with how to develop information systems, both including ICT-systems, but also the practical setting the system is put into, using an engineering approach (e.g., by developing artifacts and evaluate these in a structured manner). In CESICT although having the ICT-system in the middle of Figure 1, the focus is on the effect this system has on the sustainability of the (organizational) setting it is put into. Looking at topics from CAiSE 2023, CESICT can as specified below, have relevance for:

- Aspect of sustainability of novel approaches to IS Engineering, e.g. the social and environmental sustainability of artificial intelligence and machine learning, the environmental sustainability of Blockchain technology etc.
- Models and methods, and techniques in IS engineering: How to include sustainability aspects in requirements engineering, how to use domain and method engineering to take sustainability into account e.g., in conceptual modeling and business process modeling.
- Architectures and platforms for IS Engineering. How to use cloud, fog, and edge architectures best to reduce carbon footprint, how to handle data streams efficiently.
- Domain-specific and Multi-aspect IS engineering mention explicitly sustainability and social responsibility management.

In 2022, the work of Vitali [18] which is clearly within the area of interest for CESICT, got the Best Paper Award.

3. Project Status

The center's research and innovation activities are focused on value creation for the ICT industry including organizations which actively use digitalization to ensure sustainable operations.

The center's research will be organized according to the pentagon model in Fig. 1. Research-projects could cover one or more dimensions, and in most cases more than one level, to shed light on the *dilemmas* that arise when not sub-optimizing along one dimension (e.g., only the economic dimension). Projects only applying ICT for development of sustainable solutions in a limited domain would typically not be included under the center umbrella.

The center's research projects portfolio will be related to digitalization in different domains. They will be based on concrete use-cases from partners as well as on related research challenges formulated by the NTNU academic team. This portfolio together with collaboration, innovation and training activities will constitute a project-based ecosystem.

Currently we have around 20 PhD and Postdocs connected to projects affiliated with the center, and around 75 researchers across most of the faculties at the university on the list of loosely affiliated researchers. In addition, we are connected to GoForIT[3]; a Norwegian national network with around 10 universities, 35 IT organizations and 5 interest organizations, and we are building up the international network in collaboration with this and our international advisory board, being present at main venues such as AIS SigGreen events [13] and the community around the ICT4S-conference [14]. A number of research topics have been identified, including.

1. Sustainable digital transformations in various domains
2. Interdisciplinary research to better understanding and using the digitalization and AI for sustainability from the lenses of gender perspective, geographical dimension, and citizens' engagement.

[3] https://tankesmiengoforit.no/

3. Sensible urbanizing: A toolbox for the use of sensor data in sustainable smart cities
4. Sustainable built environments for better health and well-being
5. Pervasive and trustworthy digital technologies for evidence-based sustainability
6. Sustainable, circular, and secure e-waste ecosystem
7. The maths of sustainability in public opinion formation: Heuristics, biases, simplification, and exploitation
8. Sustainable software processes
9. Development and maintenance of IT based on sustainability requirements – Sustainability by design.
10. Life-cycle analysis (LCA) of ICT-solutions in digital ecosystems
11. Sustainability through low-code and no-code approaches to ICT
12. Sustainability practices for a sustainable software product.
13. Sustainable data governance
14. Use of Active Knowledge Models [16] to ensure learning across domain – by repurposing data from non-sustainable to sustainable business areas.
15. Data management and enterprise management for sustainable smart cities [4]
16. Cities as learning innovation ecosystems - the role of ICT to support learning within and across cities.
17. Sustainable AI [18]
18. Responsible and explainable AI
19. ICT in the circular economy [21]
20. Ensuring democratic control of platforms in digital ecosystems such as those provided by Facebook, Google, Microsoft and Apple.

Several of the above topics are currently being pursued in ongoing projects, including 1, 5, 9, 15, 16, 17, 18, whereas ongoing applications are targeting additional areas.

Instead of setting up a total budget for the center at this stage, the following key performance index (KPI) are set for the next five years.

- 50 master- and bachelor theses related to sustainable digitalization.
- 15 proposals to the Norwegian Research Council (in collaboration with partners and the proposed research activities above)
- 15 proposals to Horizon Europe (in collaboration with partners and the proposed research activities above)
- 15 PhDs/Postdocs funded.
- 10 funded projects by the industry and public sectors (in collaboration with partners and the proposed research activities above)
- 10 Seminars/Workshops
- 5 FRIPRO (basic research) proposals (based on proposed research activities above)
- 2 ERC grant proposal (based on proposed research activities above)
- 3 International conferences/workshops
- 1 MSCA Doctoral Training Network proposals
- 1 SFI/FND proposal (based on proposed research activities above)
- 1 SFF proposal
- 1 EVU master program related to IT for sustainable development.

The success of the center will be measured by supporting existing initiatives and contributing to the launch of new research and development projects in the field of sustainable digitalization, which will reduce CO_2 emissions in a social and economically sustainable manner by focusing on the research areas addressed above.

The anticipated impact of the center:

- ***National policy priorities:*** The center results promote research, innovation, development, and utilization of new technologies in sustainable development. Using the GoForIT-network we will use results as part of influencing Norwegian policy and new digitalization strategy being currently developed.
- ***Global challenges*****:** Depending on the application domains of projects linked to the center, we envision impact on a number of United Nations (UN) Sustainable Development Goal (SDG) in particular:
    - GOAL 3: Good Health and Well-being
    - GOAL 4: Quality Education
    - GOAL 5: Gender Equality
    - GOAL 9: Industry, Innovation, and Infrastructure
    - GOAL 11: Sustainable Cities and Communities
    - GOAL 13: Climate Action
- ***Innovation based growth in ICT sector:*** The collaboration in GoforIT makes us confident that the industry realizes the need to change practice in a more sustainable direction. By supporting the Norwegian industry to change in this direction early, they will become more competitive also on an international market.
- ***Optimize planning, design, operation, and maintenance:*** The center provides developers and operators with tools and knowledge to optimize development and governance of ICT.
- ***Creating high quality employment:*** The center will provide Norwegian stakeholders with high quality competence base to offer sustainability-centric and safer solutions.
- ***Strengthening the uptake of research and innovation in society*****:** Through the already ongoing collaboration with Norwegian industry through GoForIT, interest organizations, and public sector.
- ***Horizon Europe:*** Clusters 4 (Digital, Industry and Space) and 5 (Climate Energy and Mobility) in Pillar 2 alone has a total budget of 30 billion Euros and is the main areas of projects supporting the twin transition.
- ***Creating and disseminating high-quality new knowledge*****:** The center will promote publications in open access high-impact peer-reviewed scientific journals, as well as participation at conferences and international events.
- ***Future Technology Education:*** NTNU has a national responsibility to educate candidates with up-to-date knowledge so that they can serve the nation better. The center-results will be implemented in NTNUs strategic initiative to revitalize technology studies , in particular how it is followed up in SFU Excited[4] which has as a central part how to ensure that the ICT-studies include sustainability aspects. The center-results will enhance the combined sustainability and digital competences of our students/participants who are enrolled for individual courses or complete bachelor, master or PhD education through both ordinary education and lifelong learning programs.
- ***Strengthening competence and capacity*****:** The center will through the recruitment and educational program provide the industry with highly qualified personnel at BEng, MSc, and PhD level. These candidates are expected to serve society for approx. 40 years of their work-life, taking on various roles to support the green shift in Norway

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