SRC – the societal and economic impacts of the consortium project

**THE FIRST OBJECTIVE**

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| **The name and abbreviation of the project**: **Cloud computing as an enabler of large scale variable distributed energy solutions: Bright Clouds – Dark Clouds (BCDC)** |
| **The consortium leader**: Rauli Svento |
| **1. The impact objective**<br>LARGE SCALE INTEGRATION OF RENEWABLE ENERGY RESOURCES INTO THE ELECTRICITY SYSTEM (consortium level impact)<br>The BDCD Consortium aims to show how cloud computing based smart ICT solutions enable the transition into a two-sided, flexible smart energy system. This includes increasing share of intermittent production in the system, smart metering and housing technologies together with new digital services. We shall develop system models that will be used to simulate the type and effectiveness of our solutions. Cloud computing based smart ICT solutions open up new export possibilities based on scalable solutions. Through the new system's cost efficiency, the transition enables reducing $CO_2$ emissions and increasing competitiveness. To responsibly succeed in the inevitable change, we aim to enable the missing links for the energy system through active interaction with co-operators and general public. The objectives (O) for this system level interaction in our Interaction plan are: Integrating knowledge and knowing of the researchers of the Work Packages (WPs) 1 to 5 and the partners involved during six years (O4); Setting up, developing and maintaining a knowledge base of the BCDC Community (O5); Informing political decision makers about the outcomes of the BCDC Consortium (O6); Enhancing changes in regulations and legislation related to energy production and market principles (O7). |
| **2. What program questions (A, B, C, or D) does this objective address?**<br>A.*In the case of a concrete disruptive technology, how is it manifested in Finland and what are its potential benefits?*<br>Transition of the traditional, inflexible energy system into a two-sided, flexible smart system requires the utilization of cloud computing based smart ICT solutions, which we see as the concrete disruptive technology. The objective one relates to the system level. Currently two ways are used to tackle the intermittency and integration cost questions at the system level. Some countries like the UK and Ireland have chosen to start a capacity market as a side market for the generation market. Needed amounts of back-up capacities are bought from power plants by auction mechanisms. These capacities must then exist when they are called for production suddenly. Other countries like Germany have decided to trust on demand response instead. Our results show that demand response can function as an efficient instrument for solving the intermittency problem in energy only markets. However, it is also clear that the whole system must be used in a coordinated manner to reach this goal. This highlights the importance of co-operation between the Transmission System Operators (TSO) in the future. Our collaboration with Fingrid supports this goal. |
| **3. Means**<br>The rapidly developing use of renewables cannot adapt to the current electricity system and energy market in optimized ways without building the missing links. This new situation of energy production will increase uncertainty in the system and lead to system level-expenses that this far have not been taken into account. BCDC aims at finding out, what kind of expenses and at which level can be expected in Finnish and Nordic conditions. We will develop the intelligence of the |

electricity system and digitalization-enabled cloud services with market-based solutions that secure energy production in varying environments at minimal cost.
The means for building understanding and solving the missing links are based on our research and regular meetings face-to-face. The workshops for the WPs have been productive, and when organized together with the Advisory Board (AB), provide crucial knowledge at the system level. These were initiated in our Kick-off in late-2015, also participated by our strategic partners Finnish Clean Energy Association and the Carbon Neutral Municipality Forum, and in our Kick-off for the AB in early-2016. The face-to-face meetings with the strategic partners and the AB allow immediate contact with market operators, which enables *productive interaction* and effective realization of our results. Discussions go on through Slack and Basecamp, and Basecamp is also used for project information sharing and management and documenting the joint development processes. In 2016 we organized a series of three intensive co-creation workshops for further development, first with the AB, then with the WPs only, and again with the AB. Besides determining the model family to be used, the discussions have prevented siloes within our community. Our multidisciplinary, multi-professional and multi-organizational communication was enhanced by Prof. D.J. Johnson's, the Univ. of Kentucky, USA, visit in 2015, and supported Postdoc A. Suorsa's research on interaction in knowledge creation within a R&D community (PhD thesis accepted 2017). Knowledge creation is enhanced by developing further the knowledge-base, also evident on our website's extensive content, and our multidisciplinary terminology 'Clean Energy Research (CER)' compiled to enable sharing each WP's unique expertise within BCDC and beyond (see Unintentional impacts). This aligns with our Interaction plan's O5 'developing a joint knowledge-base'.
We are closely evaluating and strengthening the foundations of our system models and developing guidelines for building them. In our evaluations, we use our best knowledge from several disciplines in international research collaboration. Through this, we pursue guaranteeing that the agent-based and analytical modelling can be combined into working electricity system level models for credible solutions. Different approaches are needed for relevant analyses of different modules of the day-ahead market, the intra-day market, and the balancing market. We have succeeded in organizing the activities and tasks for reaching this goal. Our multidisciplinary research community is *productively interacting* on the nature of the system models. Without power engineering we might have focused only on the day-ahead market. In the workshops, the need to model also the balancing market became obvious. This broadening of our view and research agenda helps us interact with Fingrid more accurately. We are following the development of electricity systems in various countries through close international collaboration with Prof. Gowrisankaran and Prof. Reynolds and their group from the Univ. Arizona, Tucson, USA, which was visited by the PI Svento and Prof. Kopsakangas-Savolainen and two Doctoral students in 2016 (see Tarina: http://www.bcdcenergia.fi/tarina/osa-4/ ). Prof. Gowrisankaran's team has analysed the role of large scale photovoltaic power production in Arizona and now they are jointly with us interested in looking at the role of wind power in the hydro dominated Nordic power market. BCDC collaborates with the Potsdam Institute for Climate Impact Research, visited in 2016 by a Doctoral student with a presentation on their Research Domain IV: Transdisciplinary Concepts & Methods. This model was further discussed in a workshop in 2017. Our model serves as a multilayer model of the smart grid. The aim of the combined model is to better understand influences of the market system on the physical grid and possible feedback loops to be created for guaranteeing stable market working conditions. A researcher from the Univ. of Campinas, Brazil, visited Oulu and two researchers of WP2 Brazil in 2015 and 2016. A researcher from the Univ. of Helsinki visited NEC Laboratories in Heidelberg, Germany, and a researcher from Tartu visited the Finnish Meteorological Institute (FMI) in 2016.
Energy systems are embedded in BCDC academic teaching: a workshop on radiative transfer modelling and Summer School were held at the Univ. of Helsinki in 2016. A three-course learning module 'Smart Grids' including the learning material was jointly produced by WP1 and WP2 at the Univ. of Oulu, Centre of Wireless Communications.
(see http://www.oulu.fi/energy/node/41323 ).

**4. Observations on concrete effects**

To solve the first impact objective, we have pursued developing system wide simulation and optimization models for analyzing the effects of increasing shares of renewables in the electricity system. The interaction has been open, evaluative and reflective, and thus effectively guarantees the quality of our research work (O4). Our terminology 'Clean Energy Research' enables innovating on multidisciplinary basis and collaborating towards interdisciplinary new knowledge (O5).

The Finnish TSO FINGRID published a working paper and a related report 'Electricity market needs fixing – What can we do?' in 2016. Together with the other energy related SRC consortia *Smart Energy Transition* (SET) and *Transition to a resource efficient and climate neutral electricity system* (El-Tran), BCDC delivered a joint comment to this initiative. In our comment we strongly emphasized our views based on our results and understanding of the Nordic power market (http://www.smartenergytransition.fi/wp-content/uploads/2016/09/STNn-kommentit-Fingridin-keskustelupaperiin-15.09.2016-.pdf ). (See Impact Narrative 2.) Together with SET and El-Tran we also published a policy brief related to coal-neutral development (http://www.bcdcenergia.fi/wp-content/uploads/2018/06/Policy_Brief_Hyodynnetaan-energiamurros-ja-luovutaan-fossiilisesta-energiasta-17052018.pdf).

BCDC also organised a workshop 'Electricity markets in disruption' together with SET, El-Tran & Neo Carbon Energy on May, 2016. Our results and understanding of various subsidies given renewable and fossil resources in Finland were actively discussed. Moreover, the idea of a round table discussion on these issues was put forward. Consequently, Fingrid has altered some of its activities after interacting with BCDC consortium (O7). According to Fingrid's Director Lindroos the changes in their pricing policy ideas are partly an outcome of collaboration with the BCDC researchers and the AB. We have also been involved in the Disruptive Technologies Program's (DTP) TECH-seminars organised by Program Director Heli Koski. The consortia of the DTP have together with *Tekniikka and Talous (T&T)* opened the *Teknologiamurrokset* series of blogs in *T&T*.

As a consequence of our active collaboration with our strategic partners negotiations with Porvoon Energia and Municipality of Ii have been successful and co-operation with both started in 2017 and 2018 (see Impact Narratives 2 & 3). A Nudging Experiment has started with Porvoon Energia and Motiva conducted by the Finnish Energy Authority. Iisisti Energinen project has been executed together with Mmunicipality Ii and SITRA.

**5. Intentional impacts**

***Impact on political decision making (Interaction objective 6) and on changes in regulations and legislation related to energy production and market principles (O7)***

The BCDC PI, Prof. Svento was invited to the hearing of the Committee for the Future, the Parliament of Finland in 2016. We have put forward our understanding of future climate policies in the Finnish Climate Panel through our two members of the panel: Prof. Maria Kopsakangas-Savolainen, now the vice-chair of the panel, and Research Director, Dr. Marita Laukkanen. Program Manager Heli Koski presented the Energy Weather Forecast to Finland's government including the Prime Minister at government's strategy meeting in spring 2016. Prof. Svento hosted a visit of the Ministry of Finance, Economics Department Director's visit to Oulu in 2015, and the visit of Senior Economic Officer and Economic Specialist from the Embassy of the United States of America in 2016. In 2018 PI Svento presented a BCDC Keynote in the Finnish Energy Authority's Renewable energy day and opened the meeting with prime minister Sipilä in the Oulu University *Seuraavat 100 vuotta* telling about basic BCDC results.

The public events supporting our view relate to Fortum's discussion 'Ilmastopolitiikan ohjauskeinot – mikä rooli kansallisella ohjauksella?', in which Research Director Laukkanen took part in 2016, and a round table discussion on sufficiency of energy efficiency in a SET seminar at Aalto University, in 2016. Prof. Svento opened the SRC's event 'Rakkaudesta tieteeseen' in 2017, and Marita Laukkanen presented BCDC ideas on subsidies for non-renewable energy sources in the second Rakkaudesta tieteeseen event in 2018. BCDC Energy participated actively

in developing the 'Ratkaisukortit' card pack and their presentation in 'Ratkaisuja tieteestä' happening in January 2019. Professor Maria Kopsakangas-Savolainen gave a keynote in Energy Authority's Uusiutuvan Energian päivä February 2109where KTT Enni Ruokamo also gave a presentation. A YouTube-video on transferring decision making from politicians to citizens and changing the EU-legisaltion to support prosumers was produced (https://www.youtube.com/watch?v=3i2GSyZ4xac). Also our report 'Survey on energy cloud application in electricity markets' takes a stand on the missing links in terms of legislation.
Dr. Niemelä is a member of European HIRLAM Advisory Committee (to steer international weather model development) and of EUMETSAT Policy Advisory Committee (to steer international weather satellite activity). Research Prof. Lindfors is a member of a solar electricity and heating construction technology committee (Aurikosähkö- ja lämpö RT-toimikunta) and of a working group of the Ministry of Transport and Communications on energy reform.
Our *Energy weather* application was opened on our website on June 13th 2016. It is also important at the system level, because the variables of wind, inflow and demand in the simulations of the hydropower producers in our model have depend on the weather conditions, and they are uncertain in the real-world electricity systems. High accuracy of weather forecasts can thus increase the value of variable renewable energy sources, as they improve the hydro-wind-demand coordination in power systems. (See Impact Narrative 2.)
BCDC *Keep on Talking* podcast series (https://www.youtube.com/channel/UCkt4jOJdUmzMwVhB17x9oUA discusses the system level questions from different angles like demand response (#1, #5a,b) and complexity of the system (#4).

**6. Nonintentional impacts**

The nonintentional impacts clearly relate to our Interaction Plan's objectives Integrating knowledge and knowing of the researchers of the Work Packages (WPs) 1 to 5 and the partners involved (O4), and Setting up, developing and maintaining a knowledge base of the BCDC Community (O5). However, as we did not plan these activities to be taken in such a way as they have emerged, we report them here.
From the initiative of the BCDC consortium's work the electricity companies Caruna and Porvoon Energia have asked their clients to provide their customer data to be utilized in our research (O4). The Caruna clientele questionnaire and asking of the permission to use their electricity metering data in research have been performed with great results. The survey reveals important aspects related to the obstacles and incentives of own photovoltaic investments and production. Over 1300 households have given their promise to use their metering data, which we now have in our possession to be used in our research. The Porvoo survey has also now been finalized with promising results. Over 1200 households participated and over 600 of them have agreed to participate in our nudging experiment.
Our modelling efforts have clearly shown the importance of multidisciplinary teams in this kind of research. Interaction between the scientific fields along with their expertise has been very fruitful. The quality of research collaboration with Prof. Gowrisankaran from the University Arizona, Tucson, USA, is outstanding (O4). He was conferred a degree of doctor honoris causa at the University of Oulu, on May 2017.
The multidisciplinary research of the BCDC consortium, was the basis for a novel terminology 'Clean Energy Research' compiled to the Helsinki Term Bank for Arts and Sciences hosted by the University of Helsinki (www.tieteentermipankki.fi). Collaboration with Prof. Onikki-Rantajääskö, Univ. of Helsinki, was initiated by Prof. Huotari, and Project researcher Tuomela employed to work on the terminology in collaboration with the researchers in 2016, and a blog about CER published by the Helsinki Term Bank for Arts and Sciences, and the Finnish Clean Energy Association. A workshop held in 2017 relates to this development (O5).
The Finnish Energy Authority has employed BCDC Energy researcher Juha Teirilä as a market analyst.

**7. Background research**

As far as we know BCDC is the first group to examine the impacts resulting from coordination between wind power, real time pricing and a large-scale energy storage. Our first system model is a simulation model of the Nordic power market. We pay special attention to hydro power so that we can optimize the use of inflows and reservoirs in a societally optimal way. The renewable resource we firstly look at is wind. A key question related to Nordic electricity markets is that we have a very heterogeneous production structure with a sizable share of hydro power included. In recent years the share of hydropower has been over 50% of the load. Hydro is interesting in this context because it is easily adjustable to sudden changes in the system. Thus, it provides a possible source for the needed adjustments when the intermittency problem of the renewable sources materializes. Therefore, we concentrate on analyzing the potential of hydro as balancing power in the Nordic and Finnish electricity markets. These issues have been discussed in a blog (http://www.bcdcenergia.fi/blogi-ja-uutiset-vesisahkoa-ja-karppausleipaa-kuluttajan-todellinen-vaikutusvalta/ ) and twitter.

Our second system-wide model of the electricity market aims at providing the basic concepts of all electricity markets including all major elements and participants. This model thus includes the spot market but also the balancing market, therefore capturing the underlying physical property that demand and supply need to be matched in the grid all the time. All details in the implementation, that needed to be decided for the model to work, are designed after the Euphemia[1] algorithm which is used across most European markets. The model is constructed as an agent-based model (ABM) where all market participants are agents. The included agents cover consumers, producers and utilities. All agents can make individual decisions based on their perceived environment and their internal state. The state of an agent might change during the simulation based on certain rules so that the decisions of an agent influence the environment, which in turn influences the state of the agent which in again influences the decisions. This makes it possible to capture basic feedback loops and dynamic behavior (see Impact Narrative 3). The role of the virtual utilities is going to be more acute in the balancing markets and this is why we need to model the whole system in such a way that all markets are included.

We aim at gaining validated results to have an impact on the public debate, energy policy, and organizational and consumer behavior. In our research, we indicate that our first constructed system-wide electricity market model captures the hydropower characteristics of the Nordic market as expected. Strong positive correlation between hydropower and demand verifies the load following ability. The negative correlation with wind power indicates that hydropower can be utilized to balance out the variation in wind power output. However, it is a demanding task for future regulators to control for the strategic behavior of hydro producers so that these important characteristics are not gamed away. Furthermore, our results related to the role of demand response as a counterforce against the effects of increasing wind power production are clear. Demand response can be efficiently utilized in minimizing wind power integration costs. The tendency of the utilization rate of thermal capacity to decrease with larger wind share can be countered with higher shares of real time pricing customers. Additionally, demand response decreases the carbon footprint of the electricity system. However, we show decreasing marginal effects from increasing the amount of demand response.

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[1] https://www.nordpoolspot.com/globalassets/download-center/pcr/euphemia-public-documentation.pdf

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