Adaptive Flexible Energy Systems for Sustainable Regional Development

Preliminary Conclusions on 'Energy Hubs' in Southern Sweden

FINAL REPORT FOR THE PROJECT SUPEREFFEKT

Version 2.0, March 2026

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About the SuperPower Project

A preliminary version of this report was produced during the years 2022–2023 by Blekinge Institute of Technology (BTH) within the project SuperPower, financed by Region Blekinge's regional development fund, the Swedish Agency for Economic and Regional Growth, and Blekinge Institute of Technology. The preliminary study results were presented to the funders in June 2023. This is the final version of the report which has been updated, further reviewed scientifically and published in BTH's report series. Reviewer was Professor Karl-Henrik Robèrt, Blekinge Institute of Technology.

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Content

Preface to the final version

This is the final version of the SuperEffekt pre-study, which has taken its form after updating and additional review. The objectives and content are, however, largely the same as in the preliminary version. This last part of the project took longer than planned but is now finally in place.

Henrik Ny and Martin Prieto Beaulieu, from Blekinge Institute of Technology, Project Owner and Project Leader of SuperPower, respectively.

Karlskrona, March 2026

Preface to the preliminary version

This is the preliminary version of the SuperPower pre-study, which has the goal of finding solutions to secure Southern Sweden's energy supply in a sustainable way in line with the goals of the EU and the region.

We are facing an irreversible climate change where we today can only see the first consequences. This may become extremely costly and change the way we live. Everyone therefore needs to contribute to reducing the carbon footprint from the energy sector while at the same time creating long-term sustainable solutions. This study gives an overview of what is possible and what must happen as soon as possible.

To build a sustainable energy system is no longer an optional alternative for society as a whole but decisive for survival, attractiveness, and competitiveness.

Henrik Ny and Martin Prieto Beaulieu, from Blekinge Institute of Technology, Project Owner and Project Leader of SuperPower, respectively.

Karlskrona, June 2023

Introduction

It is increasingly noticed around the world that it is urgent to address climate change. This is at the same time only one part of the broader global sustainability challenge, that needs to be dealt with since an unsustainable society by definition cannot survive in the long term. The United Nations has attempted to manage this through Agenda 2030 and its 17 Sustainable Development Goals (SDGs) [1]. Researchers from the Blekinge Institute of Technology has also, during 30 years in a continuous international consensus process, led the development of a well-anchored scientific strategic framework for transforming organizations and society as a whole toward sustainability (the FSSD)[2.].

The energy system has been identified as strongly contributing both to the sustainability challenge in general and to climate change. Unfortunately, the transition both in society and in the energy system is still not happening fast enough to meet the requirements of the Paris Agreement and other important global sustainability goals. However, solutions exist that can accelerate development and be economically justified. Renewable energy exists in abundance from sun, wind, and waves everywhere, and society must now make large investments in order to cost-effectively capture energy and generate power where and when it is needed. At the same time, new types of energy storage and smart energy grids are needed to handle a new decentralized, stable, and economically advantageous energy system.
During recent years, global events have occurred that underline the need to urgently address these challenges:

- The latest IPCC report[3] shows that the climate situation is rapidly worsening and that adaptation is becoming increasingly important.
- Russia's war of aggression against Ukraine has highlighted that the climate transition and security are connected, since Russia can hold the EU hostage due to dependence on Russian gas and oil[4].
- The Swedish Climate Policy Council has in every new report[5] pointed out that the transition is urgent and that planned measures so far are not sufficient.
- New political priorities in energy policy in Sweden.

The regional development strategies (RUS) in Skåne and Blekinge have also noted the increasing societal relevance of energy issues. Blekinge's RUS mentions sustainable energy as part of the solution to climate and environmental challenges in order to promote high quality of life. In the draft for the new RUS, energy issues receive increased priority with focus on promoting transition to a sustainable energy system, fully in line with Blekinge's climate and energy strategy and its action program. Skåne's RUS emphasizes the importance of innovative climate work to achieve a climate-neutral and fossil-free Skåne, and Blekinge's strategy for smart specialization is also relevant here by combining two of three specializations, tech and missions.

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[1] Agenda 2030 and the sustainable development goals (SDGs). https://www.regeringen.se/regeringens-politik/globala-malen-och-agenda-2030/

[2] The resultat from this process is described in this article: Broman G.I. and Robèrt K.-H. 2017. A framework for strategic sustainable development. Journal of Cleaner Production, 140: 17-31.

[3] IPCC. 2022. Sixth Assessment report – Mitigation of Climate Change https://www.ipcc.ch/report/ar6/wg3/

[4] von der Leyen. 2022. "Det talade ordet gäller" https://ec.europa.eu/commission/presscorner/detail/sv/statement_22_2685

[5] See, e.g., Climate Policy Council. Annual Report 2026 (in Swedish). https://www.klimatpolitiskaradet.se/rapport-2026/

Assignment, objectives, and scope

This pre-study shall investigate the sustainability potential in designing and building so-called "energy hubs" — a sustainable and scalable concept for renewable energy production and energy storage with batteries and hydrogen. This can at times give local surplus of free renewable electricity that can be stored and used when appropriate. The American independent think tank RethinkX calls this SuperPower[6], and this term is also used in this English report version (in the original swedish report version[7], though, the term SuperEffekt was used).

It is here the energy hub concept can become an important part of the solution by providing decentralized continuous access to storage-secured renewable energy where it is most needed. Here are three reasons why this pre-study is needed:

- To further develop the project idea, to form and anchor collaboration and partnerships for an implementation project.
- To lay the foundation for identifying at least three to five strategic physical locations, starting in Blekinge and Skåne, for implementation and system design (that is, toward the electricity grid, industry, port, logistics center, city center or similar). Or a combination of one or several of these examples.
- To lay the foundation for continued financing of an implementation project for the benefit of the transition of the energy systems in Blekinge and Skåne.

Initially, an overall goal for the pre-study was to clarify how to prepare for the pilot facility in the implementation project. This facility was intended to become an energy hub that at a later stage could be scaled up and commercialized together with participating companies. During the later years, however, we have had a rapid and transformative development in the energy field. We are moving toward new flexibility markets, electricity prices fluctuate strongly, and changed behavior patterns have at times reduced energy use unexpectedly much. It has also become clear that possible new energy hubs will need to be synchronized with, for example, the special needs of ports, shipping, and other energy users. This has led us to update the goal of the pre-study to first develop an adaptable methodology for building energy hubs in different contexts rather than proposing a specific pilot facility at this stage. This requires, among other things, concrete sustainability modeling where the development needs of different sectors are weighed against each other.

We therefore formulated the following updated detailed objectives for the pre-study:

- Establish collaboration and partnerships around the energy hub concept.
- Identify criteria for where and how energy hubs should be built.
- Prepare for a future implementation project.

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[6] See for example this video by Adam Dorr from RethinkX (Rethinking Energy 2020-2030: 100% Solar, Wind and Batteries is just the Beginning): https://www.youtube.com/watch?v=6zgwiQ6BoLA

[7] Ny, H. and Prieto beaulieu. 2026. Adapted Flexible Energy Systems for a Sustainable Regional Development. Preliminary Conclusions on 'Energy Hubs' in Southern Sweden. Blekinge Institute of Technology. Research Report 2026:01.

Methodology and Working Approach

The pre-study uses the framework for strategic sustainable development (FSSD), which includes both a general operational definition of ecological and social sustainability as well as a planning process in four steps (A, B, C, D) for integration in the strategic work of companies and other organizations (figure 1). The method thus includes the Swedish Agency for Economic and Regional Growth's (Tillväxtverket) three sustainability aspects (environment, equality, and diversity) and adds the economic/strategic dimension in a robust process methodology. The four steps of the pre-study include close cooperation and dialogue with both already initiated and newly associated partners from start-up companies, regional small and medium-sized enterprises, and the public sector:

- Step A. A vision for the energy system as a whole is developed and translated into concrete goals within the frames set by the sustainability principles (SPs) of the FSSD:
  - **No systematic increase of pollution of nature** (corresponds to SP1 and SP2 in the FSSD)
  - **No systematic dispolacement or physical destruction of nature** (SP3 in the FSSD)
  - **No systematic structural social obstacles to trust between people** (SP4-SP8 in the FSSD)
- Step B. The current reality of the energy system is mapped and analyzed in relation to the vision and goals modeled within the SP frame above.
- Step C. Possible solutions that can enable the vision and goals for the energy system are identified and listed.
- Step D. Based on the overview of solutions from step C, a preliminary step-by-step plan is developed for an implementation project concerning a methodology for energy hubs. The solutions are selected from the list in step C and placed on a timeline so that each solution prepares the ground for the next in a cost-effective way. In this way, the foundation is created to solve balance needs between production, storage, and use of energy at different levels of the energy system.

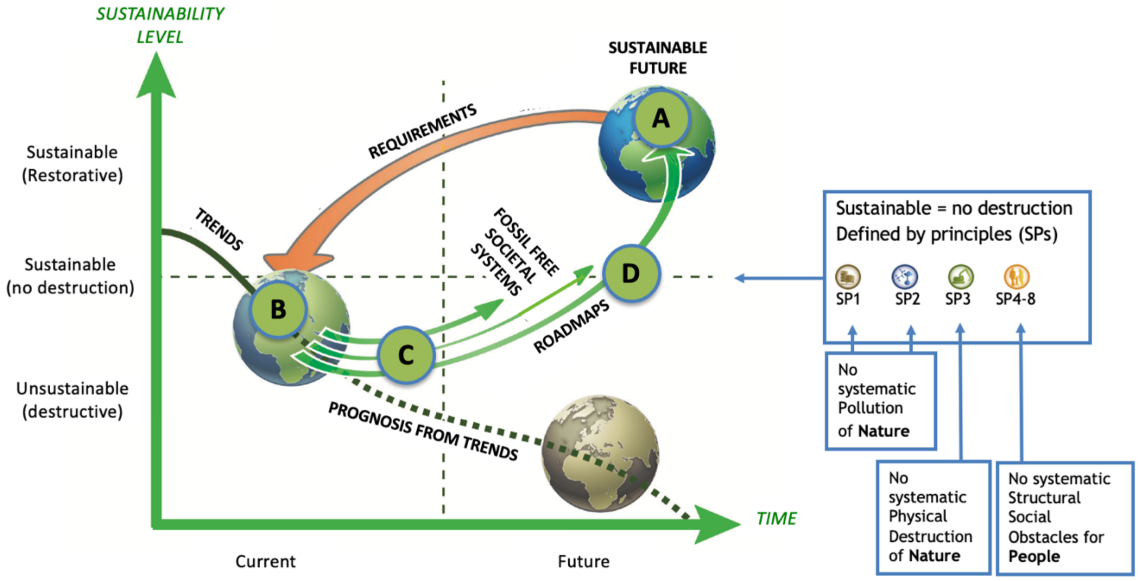

Figure 1. How prognoses and trends indicate that the current unsustainable society moves towards deeper unsustainability and destruction while a desirable transition to a fossil free and regenerative sustainable future can be planned by (step A) define a future vision that does not violate the SPs, (step B) map the requirements from the vision against the current reality, (step C) list possible new interventions and solutions and (step D) combine the interventions into roadmaps that can bridge the gap between the current reality and the vision (based on an illustration by Stefan Borell).

The four steps (A, B, C, D) thereby are the main activities of the project and they also include a number of more concrete sub-activities. The ABCD process has been tested in many organizations and planning projects worldwide and is carried out iteratively as the original plan develops in reality. That is, the process is repeated regularly to adapt to short-term changes in the external environment without disturbing the logic, the robust underlying structure, or the implementation in practice.

To ensure long-term impact and implementation of results, the activities of the pre-study are complemented with a main activity focusing on external communication and dissemination of results with collection of reflections. The main target groups for dissemination within and beyond Blekinge have been identified among the project stakeholders. These include (1) Owners of high-power loads such as logistics hubs, ports, property owners, cities, and industries; (2) Local and regional energy companies; (3) New actors on the market such as solar suppliers, battery suppliers, and hydrogen suppliers; (4) Political decision-makers in municipalities and regions. Activities for dissemination include:

- Continuous dissemination through the activities of the pre-study together with the project stakeholders and their networks and social media channels
- Targeted communication efforts through 1-2 debate articles
- Broader dissemination dialogues at relevant conferences together with the stakeholders
- Continuous follow up through incoming reflections

Step A. Vision and Goals

Requirements on energy system sustainability visions of Sweden, Blekinge, and Skåne

The sustainability vision must meet the full set of requirements linked to the sustainability principles (SPs) of the FSSD:

- **No systematic increase of pollutants in nature (SP1-2).** To limit emissions across the whole value-chain.
- **No systematic physical displacement and destruction of nature (SP3).** To no longer let surface use displace or destroy nature at all.
- **No systematic structural social obstacles to trust between people (SP4-8).** To meet the energy system requirements of companies and private citizens (e.g. functioning energy and power services that do not contribute to health problems and discrimination).

In addition, during the transition to the future energy system we must strive for:

- Controlled societal costs and resource use through well-balanced investments.
- Balance between weather conditions, user needs, and flexibility in renewable production, storage, and transmission.
- Resilience against previously known and new external threats such as war, sabotage, and worsening climate change[8].

A future vision that should live up to all these requirmeents is concretized below[9]:

[8] Russia's war of aggression against Ukraine for example gets both regionalö and global consequences. The latest reports from the IPCC and the Swedish Climate Policy Council also show that climate change is accelerating and that both emission reductions and climate adapttions must be accelerated.

[9] The future vision has also been described in the first opinion piece of the pre-study: Ny, H., Prieto Beaulieu, M. and Robèrt, K.-H.. 2022. Look Up! We Can Get a Sustainable Energy System. https://miljo-utveckling.se/debatt-lyft-blicken-vi-kan-fa-ett-hallbart-energisystem/

Future Vision – Overarching for Society

Society has undergone extensive energy efficiency improvements and a transition to technologies that fit within the sustainability principles. The new approach has eliminated continued increase of pollution (e.g. from greenhouse gases) and moved on to reduce emissions to levels that nature can absorb.

Buildings are handled with a systems perspective, considering connections to industry, transport, energy and other societal sectors, and digitalization allows smooth upgrades towards such integrated societal sectors. Land use is planned in a wider system perspective, not only for buildings and infrastructure but also for supporting systems such as forestry and areas for capturing primary energy in a sustainable way. This becomes especially important when nuclear and fossil energy have been phased out. The increasing land dependence for capturing sustainable primary energy from free flows is included in planning so that such systems (solar cells, wind power, wave power, hydro power, etc.) can be efficiently integrated with the rest of society[10]. At all levels, self-sufficient subsystems contribute to the health, well-being, independence, empowerment, and resilience of individuals, companies, and society. The future energy system must therefore function and communicate between and within different system levels (see figure 2).

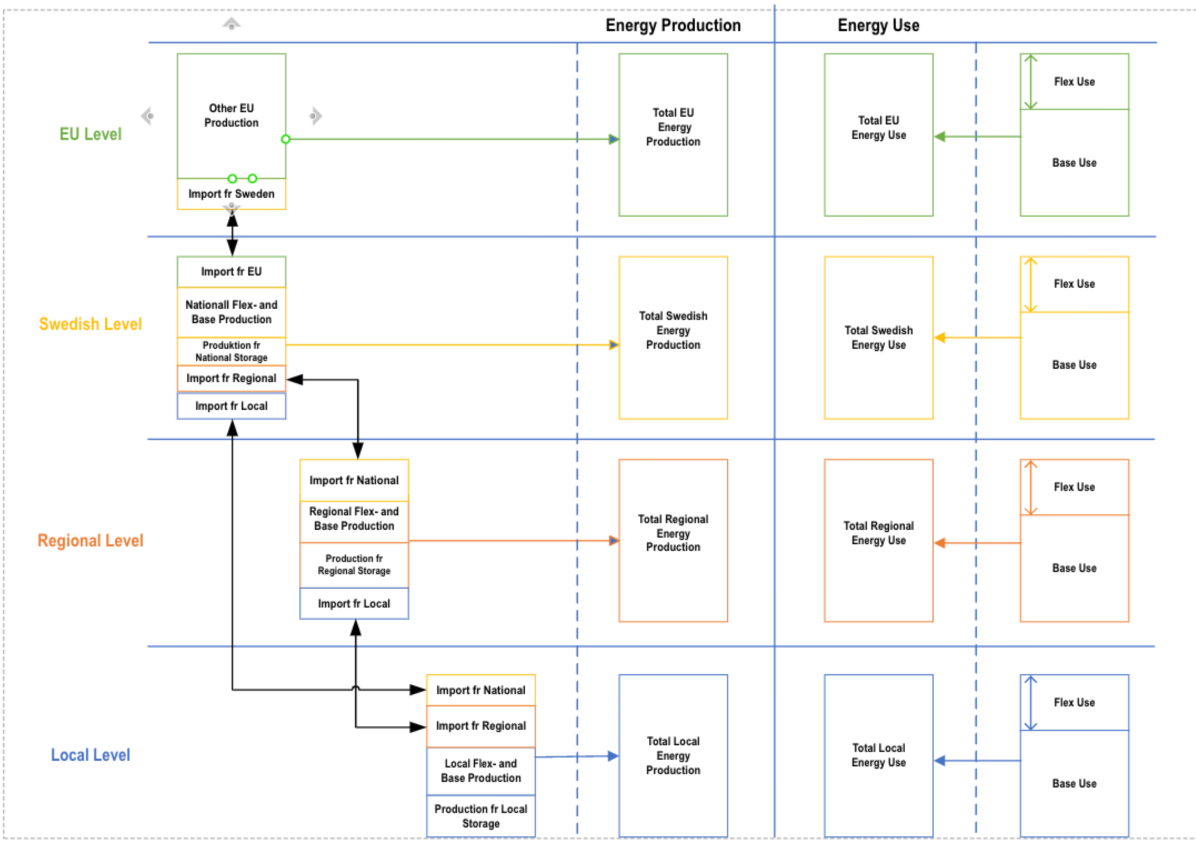

Figure 2. Sketch over flexibility services for production, storage and use of electric energy and exchanges between the different levels of the energy system.

[10] This vision of the future surfaced after an overarching modeling of future requirements that follow from the sustainability principles. It indicates that there is currently a shortage of societal planning that takes into account the likely upcoming fight for natural surfaces. This is because large surfaces will be required also in the future so that biological diversity will be able to continue driving both the biogeochemical natural cycles and providing food for a growing population. On top of this it is also expected that future operation of a renewably based energy system will require substantial surfaces.

Future Vision – for the Energy System and User Behavior at Different Levels

- ***At the buildings level,*** strong efficiency improvements and installation of energy hubs with solar panels and local energy storage in batteries, hydrogen, and similar solutions have made buildings self-sufficient in renewable energy. Buildings are also interconnected with each other, with electric vehicles, and with the electricity grid. The buildings and their neighborhoods therefore also become self-sufficient and represent the smallest-scale example of the new energy hubs. This also creates the foundation for a robust system at municipal, regional, and national levels.

  Users have become accustomed to behaving in an energy-efficient way (defrosting refrigerators and freezers, ventilating efficiently in winter, etc.), and they place controllable energy consumption (for example washing and drying clothes) during the hours when the electricity price is lowest. They also allow buildings and electric vehicles to assist each other so that electricity is produced, stored, and used in an optimal way. The planning horizon is mainly on a daily and weekly basis, but some buildings that have the more expensive hydrogen storage can also plan on a seasonal basis, for example from summer to winter.

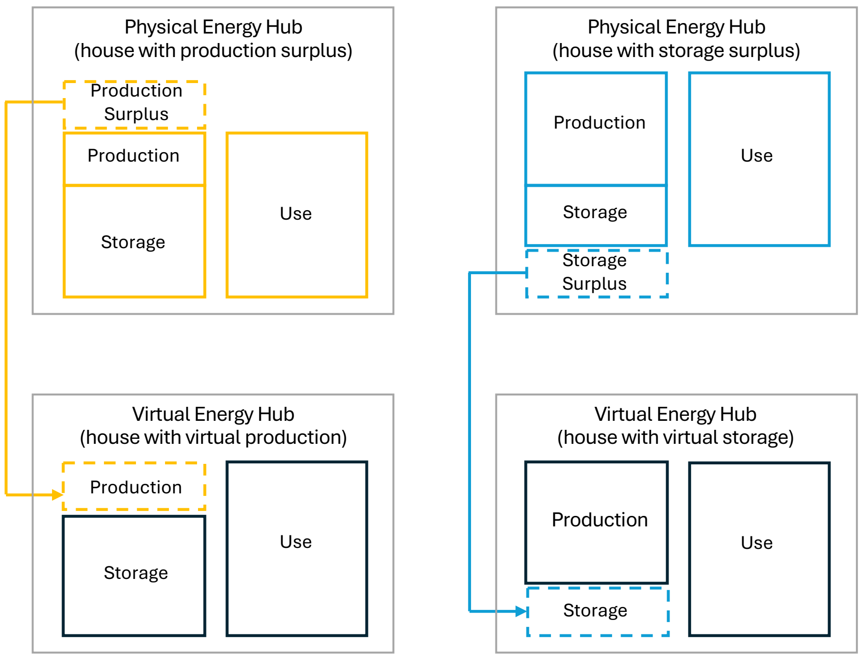

Figure 3. Sketch over how physical energy hubs (in this case houses) with a surplus of production or storage capacity can help to create functioning virtual energy hubs at other locations.

- ***At the municipal level***, resource and energy efficiency has increased through dense, mixed-use cities that reduce transport needs and focus on renewable electric public transport for the transport that is still required. Energy hubs have also been built at this level, where existing and new solar parks, wind power parks, and wave power plants have been combined with energy storage, mainly based on batteries and hydrogen, that can support the energy system for several days. Some older combined heat and power plants also remain in each municipality, at least during a transition period, to act as reserve power plants using biofuels when needed. The energy system and the new energy hubs operate efficiently, where new aggregators on daily, weekly, and seasonal levels combine the capacity of different energy production, storage, and energy use facilities into larger units on the new flexibility markets.

- ***At the regional and national levels*** there are larger renewable energy production facilities such as hydropower plants and offshore wind farms. The energy hubs at this level combine renewable energy with large industries, for example fossil-free steel production plants, that have built energy storage on a seasonal scale, mainly hydrogen-based, that can support the entire electricity system for weeks. The energy system, the large industrial energy users, and the new energy hubs operate efficiently, where the planning horizon becomes seasonal because of the large scale of the storage.

Step B. Current Reality Analysis

Current Reality – Overarching for Society – Costs and Other Sustainability Effects

Planning of buildings and construction for sustainability is weak, and energy efficiency has low priority. Buildings are handled without considering the whole and possible connections to other systems, meaning that a system perspective is missing. As a result, we have unsustainable emissions (e.g. of greenhouse gases). Traditional societal planning does not take a long enough perspective to control land use efficiently for buildings, infrastructure, and supporting systems such as forestry and agriculture. This is necessary not only to maintain the function of the biogeochemical cycles and increase sustainable food production, but also to assess the areas needed for future sustainable production of materials and primary energy for society.

Energy supply today has increased the share of renewable energy but still partly depends on nuclear power and fossil fuels, which involve increasingly expensive and environmentally and politically risky handling upstream and downstream in a linear fuel chain. Upstream because fuel resources are depleted as they are used, and downstream because all fuel use requires increasing costs to handle their consequences. Biofuels have replaced some fossil fuels, but there is a large potential, and even a need, for land-use planning that first ensures the needs of nature’s cycles and biodiversity and food production, and only after that uses forest resources for energy, since forest raw material can be used much more efficiently for society than as fuel.

At all levels, the centrally controlled energy system, and continued investments along the unsustainable path, make individuals, companies, and society vulnerable to economic and geopolitical disturbances. This creates major short-term challenges for health and well-being, and requires truly strategic investments that not only solve urgent problems but also create a profitable foundation for solutions that can be scaled up according to the future vision in step A.

Current Reality – for the Energy System and Users at Different Levels – Costs and Other Sustainability Effects

- ***At the buildings level,*** a small but growing share of buildings has been improved and installed solar panels and local energy storage, but this is still relatively uncommon. The electrical systems of buildings are not optimally interconnected and therefore still act as isolated islands that are vulnerable to price shocks and power outages and unable to support the electricity system at higher levels. Users often waste energy, for example by poor defrosting of refrigerators, unnecessary ventilation during winter, and by not moving controllable energy use to the hours when electricity prices are lowest. Increasing e-commerce with fast deliveries increases the need for freight transport and makes the situation more difficult.

- ***At the municipal level,*** communities are still planned inefficiently in terms of resource and energy use. Total transport demand increases, and public transport becomes harder to provide because detached housing and low-density development spread at the expense of more efficient land use. Solar and wind parks are starting to be built, but combined heat and power plants based on fuels are still common key facilities at this level. The energy system and the electricity grid are mainly operated according to the old centralized control model, which already causes problems in making use of electricity from new micro-producers.
- ***At the regional and national levels***, electricity production is dominated by a few large nuclear and hydropower plants, while some larger wind parks have been built on land. Offshore wind is still uncommon. Industry mainly relies on these large-scale facilities for energy supply. The energy system and the grid operate according to the old centralized control model, which works operationally but it also leaves a large unused potential for savings that could have been done with small investments. At the same time larger investments in new technology and infrastructure are required to prepare for the future.

Step C. New Possible Future Solutions

Here we focus on new approaches to the energy system. Below are described expected effects of new possible future solutions to model and evaluate regarding renewable energy, storage, system optimization, and integration that can function as intermediate steps during the transition from the current state (step B) to the future vision (step A).

Solutions – Overaching for Society – Costs and Other Sustainability Effects

- ***Societal planning*** needs to be redirected to drive energy efficiency and the sustainability transition as a whole. This includes planning dense and mixed-use cities to reduce transport needs and make public transport easier to provide.
- ***Laws and regulations*** must be adapted and expanded within Sweden and the EU to pave the way for energy efficiency and the new renewable-based flexible energy system. This includes:
    - Strengthened trade across borders but reform of the electricity trading system in order to reduce the risk of extreme price shocks.
    - Simplified and shortened permitting processes. Authorities that grant permits should, for example, work in parallel, and one authority should have the main responsibility to hold together the overall process when important transition facilities are to be built.
    - Positive influence and cooperation at the front edge to support the development of a European regulatory framework with flexible production, storage, and use of energy.
- ***New business models*** need to be developed together with the technical development in order to clearly and efficiently provide integrated services that offer efficiency improvements, upgrades, and rebuilding of energy users' facilities.
- ***Municipal energy advisory services*** need to be strengthened and expanded. This is especially important to guide private individuals and small companies, who do not have their own expertsise, through the complex transition in the energy field.
- ***Education*** of key competencies for the transition must be scaled up quickly and strongly, since lead times in this area are long.
- ***Financing models*** must be developed so that risk-willing capital can support the transition and share the gains that this can provide both in the short and long term.

- ***Investments in key infrastructure*** must be prioritized to give the greatest possibel return on the investments During the transition, existing facilities must be used in a socio-economically optimal way while new ones are built. Examples of important investments:
    - Efficiency enhancing measures such as additional insulation and upgrading of appliances in buildings.
    - New renewable energy production, for example solar panels and wind parks.
    - Energy storage resources such as batteries, hydrogen storage, and similar solutions added at different system levels.
    - Digitalization of electricity grids at all levels in order to enable control in all directions within and between system levels.
    - Early consideration of how a more optimized planning and implementation structure also requires phasing out or reshaping structures that *cannot* be scaled up in a future perspective.

Solutions – for the Energy System and Users at Different Levels – Costs and Other Sustainability Effects

- ***At the buildings level,*** the focus is on efficiency improvement and upgrading by installing solar panels on roofs, giving old electric-vehicle batteries a new life as backup systems for buildings, equipping electric vehicles with solar panels, and connecting them via smart microgrids to the buildings and the grid in order to provide extra energy storage capacity (see figure 4)[11]. These technological advances have also been accompanied by new economic collaboration forms like Energy Communities[12], sector-wide collaboration actors like Powercircle run flexibility-focused projects in this area[13] and new EU legislation has made new parallel microgrids legal[14].

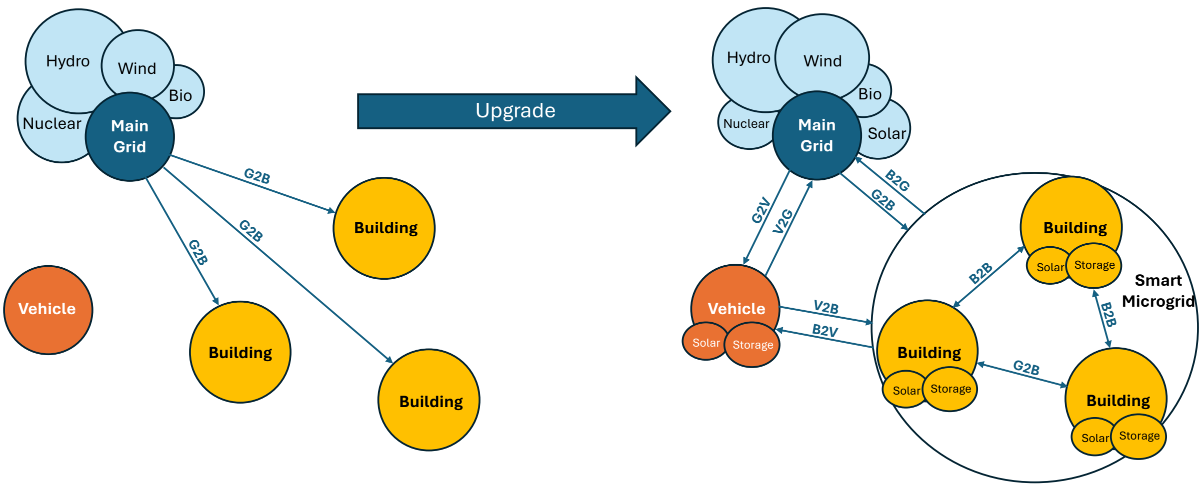

Figure 4. How upgrades at the buildings level can lead to efficient decentralised integrated systems to support all of society

- ***At the municipal level,*** societal planning is reorganized for high resource and energy efficiency. Densification and mixed functions reduce total transport demand and make public transport

[11] Concrete solutions are already appearing in this area. 'EnergyNet' is for example tested in Lund, Sweden, using smart energy routers and a new 'Energy Protocol' to let production and storage capacity for electricity be shared between users via new parallel smart microgrids (see https://www.globalurban.net/lund-sweden).
[12] See more about Energy Communitites at EU websites: https://energy.ec.europa.eu/topics/markets-and-consumers/energy-consumers-and-prosumers/energy-communities_en
[13] See more about Powercircle and their project Flexability: https://powercircle.org/flexability/
[14] Key components of this shift include the **revised Electricity Market Directive (EU) 2024/1711** and the **Electricity Market Design (EMD) Reform (Regulation EU 2024/1747)**, both of which entered into force in 2024.

easier to provide. The number of medium-sized solar and wind parks increases strongly, and the role of combined heat and power plants gradually shifts toward providing backup when needed.

- ***At regional and national levels,*** strong efficiency improvements are made in large industrial facilities, and large-scale renewable electricity production is expanded, mainly solar parks, wave power, and offshore wind, together with energy storage such as hydrogen storage and pumped storage. Flexible, controllable energy use is also expanded, for example server halls and fossil-free steel production, which also provide flexibility to support the grid on a seasonal basis. At the same time, old nuclear power is gradually phased out when the plants become uneconomic to operate and can be replaced by cheaper renewable electricity[15].

Step D. Prioritized Solutions and a Preliminary Plan for an Implementation Project around a Methodology for Energy Hubs

How We Think Around Prioritizing Solutions

The prioritized solutions are those that give the greatest effect for the effort and that can align with already ongoing strategies while also meeting the strategic development toward relevant sustainability criteria.

The analyses in this pre-study show that there are unused potentials that could increase the speed of the transition. Requirements are increasing to phase out fossil fuels and energy, while national energy security requires especially rapid phase-out of fuels and energy from dictatorships. This also increases the need for energy efficiency[16] and efficient transport[17], which has been given higher priority in the transtion planning both in the EU and in Sweden. Strategies and measures for climate adaptation must now also be developed at all levels. This is encouraged and accelerated by the state, and the municipalities have responsibility for physical planning. It is therefore necessary for them to integrate these efforts and adjust their strategies to achieve synergy effects and move toward the goal. Method development should be prioritized. We propose a four-step principle for the energy sector that favors cheaper upgrading of many existing facilities instead of only building new ones at a higher cost[18]:

- Step 1 — Rethink
- Step 2 — Optimize
- Step 3 — Rebuild
- Step 4 — Build new

We also, in line with the above, want to highlight the need to develop modeling methods that aim at reaching a future vision (step A in the ABCD process) where land requirements for nature's basic needs are respected while society can operate without nuclear and fossil fuels. Such modeling can

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[15] For an overarching study of the sustainability advantages with an energy future with focus on energy efficiency och renewables compared to an energy fúture with focus on new nuclear power see the first opinion piece from the pre-study: Ny, H., Prieto Beaulieu, M. och Robèrt, K.-H.. 2022. Look Up! We Can Get a Sustainable Energy System (in Swedish). https://miljo-utveckling.se/debatt-lyft-blicken-vi-kan-fa-ett-hallbart-energisystem/

[16] European Commission. 2019. Energy efficiency first: accelerating towards a 2030 objective of 32.5%. https://ec.europa.eu/info/news/energy-efficiency-first-accelerating-towards-2030-objective-2019-sep-25_en

[17] Transport efficiency. https://www.regeringen.se/regeringens-politik/transportsektorn-staller-om-for-klimatet/transporteffektivitet/

[18] See also how we have reasoned similarly around the sustainability challenge in the construcion and housing sector: Ny, H and Thomson G.R. 2021. Making Climate-Positive Buildings and Building Systems Sustainable. A Study within Energy Collbaoration Blekinge. Blekinge Institute of Technology. Research Report Nr. 2021:01

support steps B, C, and D in the ABCD process. Based on the general sustainability analysis of the energy system (steps A, B and C, above), some solutions have been identified that can prepare the way for development of a methodology for energy hubs. These solutions should be implemented partly in parallel and involve both project actors and other actors in society.

Activities Before an Implementation Project

- BTH and the other project participants shall continue anchoring the vision and cross-sector cooperation beyond the project group.
- BTH shall coordinate with the Swedish Agency for Economic and Regional Growth and lead the application work for an implementation project on methodology for energy hubs.

Activities in an Implementation Project

- BTH shall lead development of a model to simulate different types of energy hubs at different energy system levels (see figure 5)
- BTH shall begin competence development among project stakeholders in systems analysis, modeling, and other tools needed for effective cooperation across sectors.
- BTH shall engage energy system experts to educate actors about requirements and solutions for new flexible renewable energy systems, including aggregation of energy production and use, legal issues, and integration of technology and management.
- Energy companies and other actors shall build pilot energy hubs to develop the technology and overcome challenges.
- BTH shall follow the energy hub pilots to identify improvements.
- Other stakeholders shall study which business models are needed in the service eco system around energy hubs.
- BTH shall lead work to secure long-term financing of energy hubs at different levels. For households it could for example be suitable to offer beneficial micro-loans and for large energy hubs public support projects may be advisable.
- BTH shall lead development of a roadmap for scaling the energy hub concept in Sweden.

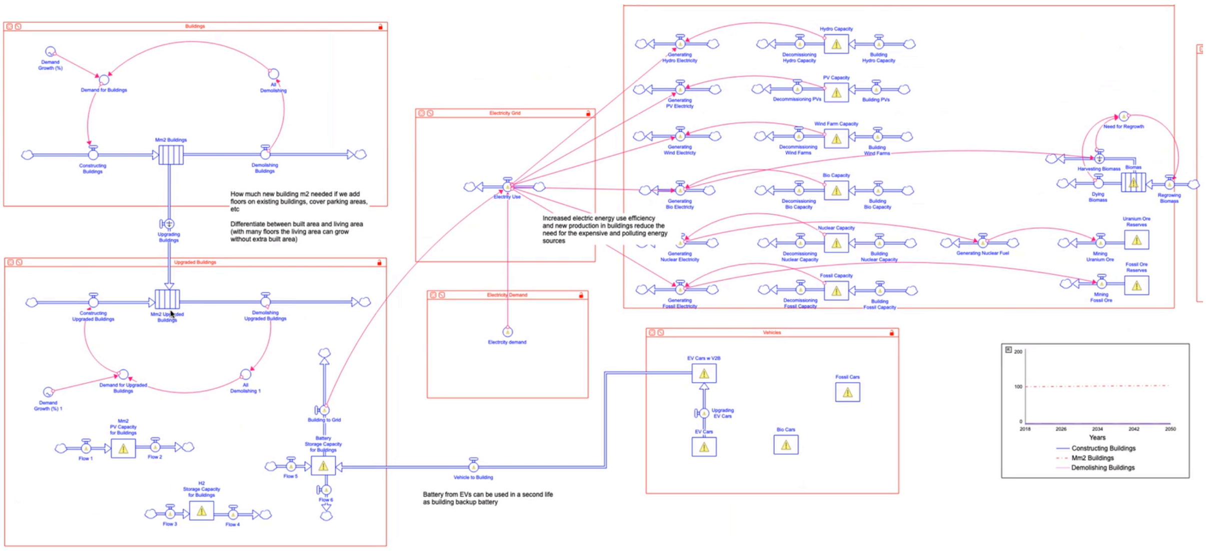

Figure 5. Sketch of a computer model to facilitate system simulations of roadmap solutions and their sustainability effects in a transition towards decentralised sustainable energy system.

Discussion and Recommendations

The Updated Goal of this Pre-Study

In the middle of a dynamic period in the energy field, the pre-study has concluded that an adaptable methodology for building energy hubs in different contexts must first be developed, rather than proposing a specific pilot facility at this stage. A concrete sustainability modeling is needed that is generic, meaning that the development needs of different sectors can be evaluated and weighed against each other. We therefore formulated the following updated objectives for the pre-study:

- Establish collaboration and partnerships around the energy hub concept.
- Identify criteria for where and how energy hubs should be built.
- Prepare for a future implementation project.

What the Pre-Study has Concluded

Insights regarding partnerships for an implementation project:

- The sectoral division that prevents efficient cooperation must be broken up since the new energy system involves many actors outside the traditional energy sector. This applies both to individual actors and to aggregated forms of cooperation.
- It is a pedagogical challenge to communicate information and knowledge, and there is a large need for knowledge development and transfer in order to involve future partners in cooperation toward scalable sustainable solutions.
- The actors already engaged in the region are well prepared to take the next step and carry out pilot projects for an efficient cross-sector step-by-step process.
- The foundation that has already been built through earlier work must therefore be allowed to continue in a systemic, systematic, and strategic way.

Insights regarding criteria for where and how energy hubs should be built

- The complexity of the energy system must not be underestimated.
- Security aspects, vulnerability, and redundancy have become more important and must be integrated into the sustainability concept when energy hubs are planned.
- The pre-study shows that energy hubs can be combined in different ways regarding size and placement of the system components. Individual energy hubs may also have different focus depending on what they are intended to contribute to the part of the system they support. This makes it difficult to predict exact dimensions.
- However, energy hubs will need to include the following components:
    - Production of renewable energy (solar, wind, etc.)
    - Energy storage (batteries, hydrogen, etc.)
    - Flexibility services (balance services for the electricity grid)
    - Modernization of business and management models

Insights regarding a future implementation project

The pre-study shows that a future implementation project will need to develop an integrated sustainability analysis and machine-learning-based modeling method in order to solve two main optimization problems:

1. How an energy hub should best be designed, dimensioned, and built.
2. How an energy hub should best be operated.

A preliminary plan for an implementation project was described in Step D, above.

The pre-study also shows that planning must go beyond the implementation project, from demonstrations and pilots to full-scale implementation and dissemination. Only then can the full potential of an integrated system be achieved. Scalability is therefore of highest priority.

Limitations of the Pre-Study

This is an initial study at an overarching level. The focus is on the conceptual dimension, and we are aware that the technical solutions would require more detailed studies.

A more detailed review would be needed, for example through a broader system-analysis workshop together with key stakeholders, in order to better understand the factors that contribute to successful implementation of the energy hub concept. Based on this, a digital model could later be developed to simulate different scenarios and evaluate efficiency, productivity, redundancy, and societal costs.

Wider Conclusion and Societal Consequences from this Pre-Study

Energy production, energy storage, and energy use can no longer be seen as separate from each other, but must be regarded as parts of a complex integrated system. Energy users in industry, transport, and the construction and housing sector at all levels should first improve efficiency as much as possible in order to ensure efficient use of resources quickly and at low cost.

At the same time, individual energy users such as buildings and electric vehicles can contribute their own energy production and storage and become self-sufficient units that are connected to support the whole electricity grid. This would make the whole country become an integrated energy system — a self-regulating system that, once built, can supply society with cheap renewable energy from continuous natural flows. Such a system would also, compared to today's centrally controlled system, be much less vulnerable to military attacks, climate change, and other disturbances. It would therefore also provide advantages from a security-policy perspective in the future.

Glossary and Supporting Definitions

ABCD (a strategic sustainability planning procedure). A four-step strategic sustainability planning procedure that operationalises the FSSD through (A) defining a sustainable vision within constraints set by Sustainability Principles, (B) assessing current strengths and weaknesses in relation to the vision, (C) identifying potential future solutions to reach the visions (D) combining the solutions into strategies and step-by-step roadmaps that can bridge the gap between the current and the vision in an affordable way.
Backcasting. Starting from a future goal, study the current situation in relation to this goal, and asking what needs to be done to achieve the goal.
Building to Vehicle (B2V) and Vehicle to Building (V2B). The energy production of buildings can directly (or indirectly via storage) charge electric vehicles. Electric vehicles, in turn, can operate as storage eller supply the building with energy.
Building to Building (B2B). Energy can be shared between buildings depending on production capacity and need.
Building to Grid (B2G) och Grid to Building (G2B). Buildings that are connected to the main grid can both receceive and give energy from/to the grid.
Building to Nature (B2N) och Nature to Building (N2B). Buildings can be integrated with ecosystem services.
Building to Mobility (B2M) och Mobility to Building (M2B). Buildings can simplify various froms of mobility.
Building to X (B2X) och X to Building (X2B). In the future there may be other new connection possibilities.
Building Systems. The surrounding geographical context of buildings that include increasingly larger scales (e.g. neighborhoods, precincts or cities).
Climate/Carbon Compensation. To compensate for greenhouse gas/carbon emissions in one context by reducing emissions in other contexts. An example is investment (via the purchase of emission shares) in renewable energy that displaces fossil energy.
Climate Change Adaptation. Adjustment in natural or human systems in response to actual or expected effects from ongoing climate change.
Climate Change Mitigation. Human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Climate Change. Change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.
Climate-Negative Building or System. A state when the initial and/or operational greenhouse gas emissions from a building or system have not been compensated by carbon capture techniques.
Climate-Neutral Building or System. A state when the initial and/or operational greenhouse gas emissions from a building or system have been compensated by carbon capture techniques.
Climate-Positive Building or System. A state when the initial and/or operational greenhouse gas emissions from a building or system have been more than compensated by carbon capture techniques.
CO2 equivalents. Emissions of greenhouse gases converted to what they correspond to in carbon dioxide emissions (usually measured in g, kg or tonnes).
Construction and Housing Sectors. In this report the former includes companies that build, renovate and demolish buildings and the latter companies and actors that manage buildings in the use phase.
Drawdown. Moment in time in the future where greenhouse gas levels in the atmosphere stop rising and start declining to the concentration of pre-industrial times.

Extraction to distribution phase (UtD). The part of a product or service's value chain life cycle that includes all activities from original extraction from bedrock or nature to distribution to the end customer.
Forecasting. To try to predict the future based on history and current situation.
Fossil-Free System. A system that is completely fossil-free. Depending on the system boundaries, this may refer to all or part of the value chain life cycle.
Framework for Strategic Sustainable Development (FSSD). A framework intended to support companies, municipalities and other organizations in contributing to society's development towards sustainability while simultaneously strengthening themselves. Two core components of the FSSD are its sustainability principles and strategic ABCD planning procedure.
Global Warming. Increase in combined surface air and sea surface temperatures averaged over the globe and over a 30-year period.
Greenhouse Gases (GHGs). Collective names of gases that, if allowed to increase in concentration in the atmosphere, contribute to increased greenhouse effect (e.g. carbon dioxide, nitrous oxide, methane, water vapor, ozone and freons).
Intergovernmental Panel on Climate Change (IPCC). International expert panel with climate researchers who compile research on the climate issue and publish regular reports.
Life-Cycle Analysis (LCA). An analysis that compiles selected sustainability effects for a product or service's value chain life cycle.
Life-Cycle Cost Analysis (LCC). An analysis that compiles selected cost effects for a product or service value-chain life-cycle (sometimes LCC is also used to denote a Total Cost of Ownership analysis).
Negative Emissions. To reduce the content of the greenhouse gas carbon dioxide in the atmosphere by technical means e.g. biochar, CCS and BECCS). (see also Carbon Capture).
Scenario. Description of a future situation and / or a development path to a future situation from a given starting point.
Paris Agreement. An international treaty that aims to limit global warming to well below 2°C and was signed in 2015 by 183 nations and the European Union.
Paris Agreement-Safe Building or System. A building or system that is becoming climate positive quickly enough to stay within its share of the carbon budgets for the construction and housing sectors.
Scope 1. Direct GHG emissions. These occur from sources that are owned or controlled by an organization or system (e.g. emissions from combustion in owned or controlled heating systems).
Scope 2. Indirect GHG emissions from purchased electricity and heat. These emissions come from the generation of the electricity and heat that an organization or system purchases.
Scope 3. Indirect GHG emissions other than from electricity and heat. This category gathers all other indirect GHG emissions from the activities of an organization or system other than from purchased electricity and heat (e.g. from the extraction and production of purchased materials, the transportation of purchased fuels and the use of sold goods and services).
Simulation. Calculations of how a system behaves under certain given conditions.
Sustainability effect indicators. Indicators of the sustainability effects of a building or any system (eg greenhouse gas emissions, surface use, etc).
Sustainability Principles (SPs). Principles within the FSSD that define sustainability.
Sustainability. That something can last over time.
Total Cost of Ownership (TCO). Total life-cycle cost for the owner of a product or service during the entire period of use.
Use Phase. The part of a product or service's value-chain life-cycle where it is used.
Value-Chain Life-Cycle (in an environmental context usually referred to simply as a 'life-cycle'). The activities that are part of a product´s or service´s value-chain from the 'cradle' to the 'grave' (e.g. extraction and distribution, use and waste management).
Waste Management Phase (Avf). The part of a value chain life-cycle where waste is sorted and disposed of (usually via reuse, recycling, incineration or landfill).

About this Pre-Study Report

The overarching purpose of this pre-study report was to investigate the sustainability potential in designing so called ’energy hubs’ – a scalable concept for energy use, renewable energy production and energy storage. This could from time to time give local surplus of free renewable electricity. The american independent think-tank ReThinkX has named this situation SuperPower. More specifically this pres-study aimed to:

- Establish collaboration and partnerships around the energy hub concept.
- Identify criteria for where and how energy hubs should be built.
- Prepare for a future implementation project.

The methodology builds on the established Framework for Strategic Sustainable Development (FSSD) and its generally applicable sustainability principles (SPs). This was done to be able to plan for energy systems in full compliance with socio-ecological sustainability while ensuring sufficient economic returns on the way there. The pre-study was performed in four steps according to the ABCD procedure of the FSSD:

- Step A. Develop a vision for energy hubs within the energy system and the sustainability principles of the FSSD:
- Step B. Map the current reality of the energy hubs in relation to the vision.
- Step C. List possible solutions that can enable the vision.
- Step D. Develop a preliminary step-by-step plan for an implementation project focused on a methodology for energy hub development within a future sustainable energy system.

The results can be summarised by that:

- Energy production, energy storage, and energy use can no longer be seen as separate from each other, but must be regarded as parts of a complex integrated system. Energy users in industry, transport, and the construction and housing sector at all levels should first improve efficiency as much as possible in order to ensure efficient use of resources quickly and at low cost.
- At the same time, individual energy users such as buildings and electric vehicles can contribute their own energy production and storage and become self-sufficient units that are connected to support the whole electricity grid. This would make the whole country become an integrated energy system — a self-regulating system that, once built, can supply society with cheap renewable energy from continuous natural flows. Such a system would also, compared to today’s centrally controlled system, be much less vulnerable to military attacks, climate change, and other disturbances. It would therefore also provide advantages from a security-policy perspective in the future.

About the Sustaintrans team

The SustainTrans Team is active within the Department for Strategic Sustauinable Development at the Blekinge Insititute of Technology (BTH) in Karlskrona, Sweden. The research is conducted in close collaboration with private and public actors with focus on accelerated transitions to sustainable transport and energy systems.

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