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Current and Future Systems of Circularity in the Energy System: Closing the energy loop

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Abstract:

The circular economy and the energy transition are two pivotal transitions in sustainable development, however, largely distinct in academic discourse. There is an abundance of grey literature on the combined topic, and as the future uncertainty of these fields remain high, we employ a futures studies methodology. Entailing a continuous data-collection covering journal articles, media, and a plethora of agency and consultancy reports; followed by three analytical phases which aims to extrapolate current developments, interpret information, and critical assessment. Which is then applied to the three horizons framework to understand these transitions together. Allowing us to theorize about the future systems of circularity in the energy sector and how these might co-evolve. Currently dominated by flows of material, followed by an increasingly service oriented system, and finally towards a transformative circular energy system. Results yield policy recommendations for supporting the integration of circular economy principles in the energy sector.

Keywords: Futures; energy; circular economy; energy-as-a-service; servizitation; three horizons.

1 Introduction

This paper utilizes a futures studies approach to conceptualize future energy systems driven by a circular transition. Combining the circular- and energy transition, to see how they synergize towards a more sustainable system. Because both transitions are pivotal to reach the net-zero target by 2050 (European Commission [EC], 2018), however, the strategies of each of these two concepts remain largely distinct (Żurawska, n.d). Presently, circular economies [CE] primarily considers energy efficiency and flows of material (Patel, 2018; see, EC, 2020). Whereas the extraction of resources and energy typically fall outside of the circular supply chain, serving as the input to be minimized (Liu & Ramakrishna, 2021). However, business ecosystems applying circular business models [CBM] have begun to consider the flows and reuse of energy as well (Aarikka-Stenroos, Ritala, & Thomas, 2021), for e.g., industrial ecosystems capturing and reusing waste heat. Furthermore, CE action and principles are largely lacking from energy companies' sustainability reporting and efforts, which Janik, Ryszko, & Szafraniec (2020) argues should be given more attention; and the EC's (2020) new action plan for CE action states its intention to supporting the development of the role of circularity in future National Energy and Climate Plans. Therefore, we explore the integration of a CE in the energy sector and system, with current examples thereof and future possibilities given evolving trends. Theorizing about the future of circularity in the energy sector, found to be primarily driven by the trend of decentralization and in turn servizitation. The disposition of this paper is constructed such that the current state of circularity in the energy system is presented as part of the findings. Whereupon theory is built regarding the evolution of said state into a more circular system, which is contrasted with a model of change strategy during the discussion.

Background

Described herein, the premise of the study and scope thereof is explicated, along with a brief theoretical outline. Outlining the strategies and principles of the energy and circular transition; and systems change through the three horizons [3H] framework. Research took place Q1 of 2023 and centres around the Nordic and European Union [EU] energy system. Concurrently, the notion of the energy sector is becoming increasingly diffused following increased sector coupling (Brown et al., 2018). A development that nonetheless corresponds with CE developments, as heterogeneous sets of actors are required to collaborate (Aarikka-Stenroos, Ritala, & Thomas, 2021). To demarcate the system of inquiry, the energy system is bound by the production of apparatus such as infrastructure and appliances; generation of electricity and heat; transmission; and utilization of electricity and heat. Whilst considering its exchanges with neighbouring systems such as forestry, waste, agriculture, and transportation.

Energy transition

A transition is a change from one form to another, at first moving from fossil fuels to renewables, which came to entail changes in everything from economic models, behavior, and values (Sovacool, Hess, & Cantoni, 2021). To achieve this, are the three pillars of the EU’s strategy for decarbonization of the energy sector: efficiency, sufficiency, and renewable energy (Zell-Ziegler, et al., 2021). Increasing *efficiency* seeks to decrease energy intensiveness, which is the ratio of gross domestic product (GDP) to energy consumption (Guevara, Henriques, and Sousa, 2021), i.e., producing more whilst using less. *Renewable* energy comes down to closing resource loops (Zell-Ziegler, et al., 2021); which has also led to a greater focus on the energy mix, to create a diversity in the supply to always ensure availability (EC, 2022). *Sufficiency* addresses societal and behavioral change to reduce the total amount of energy used (Zell-Ziegler, et al., 2021). Together these three strategies ensure that the energy supply is environmentally friendly, affordable, and secure (EC, 2022). These general strategies are followed by a host of policies and initiatives to drive this transition, such as through budgets, taxes, research, empowering local people and spurring action, and the CE amongst others (EC, 2018). The long-term energy transition is a complex and dynamic system comprised of multiple levels and actors (Doh, Budhwar, & Wood, 2021) which systems thinking supports in addressing (Saritas, 2013). To distinguish between these levels, we apply the archetypical levels of micro, meso, and macro (Ruff, 2015; Pombo-Juárez et al., 2016; Piirainen & Gonzalez, 2015). Broadly defined for the purposes of this paper, as: facility (micro), district (meso), and international (macro); e.g., wind turbine, wind park, wind power.

Circular economy transition

CE builds upon four strategies: Narrowing, slowing, regenerating, and cycling (Circle Economy, 2023). *Narrowing* the flows of resources by using less resources per product produced (Bocken et al, 2016), and using less of the product (Circle Economy, 2023). *Slowing* the resource loops entails designing for longevity through repairability allowing products to remain in cycle for longer, and remanufacturing closing the resource loop (Bocken, et al., 2016; Circle Economy, 2023). *Regenerating* aims at replacing hazardous and toxic materials in favor of natural products and cycles (Circle Economy, 2023). Finally, *Cycling* products synergize with narrowing the flow of products by reusing products lessens demand for new products which inherently require added energy and materials (ibid). A CE replaces the end-of-life of a product with the actions of reducing, reusing, recycling, and recovering materials and energy, operating on multiple systemic levels (Kirchherr, Reike, and Hekkert, 2017), however, many more concepts and *R's* have been coined.

Combined, these strategies are often seen as two sides of the same coin (Circle Economy, 2022), much akin to matter and energy. Which is reflected by the numerous definitions of the CE and their focus on the material perspective (Kirchherr, Reike, and Hekkert, 2017), however, Geissdoerfer et al's (2017, p. 759) definition brings a novel addition with "*a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops…*" This wide-spread definition consequently invites consideration of circularity in the energy supply-chain, circulating the flow of energy.

Model of change

Understanding system transitions such as energy and CE, consequently, requires us to consider boundaries in both space and time (Hodgson & Midgley, 2014). Regardless of the kind of transition, the foresight theory of 3H framework is here suggested as a suitable approach, combining futures and systems inquiry (Curry & Hodgson, 2008). Comprised of Horizons 1 through 3 (H1-3), each horizon represents its own system, copresent at any given time, see fig 1. However, to varying degrees of strategic fit following the constant change of the environment. As such, foresight can act as a systemic inquiry to try to understand these transitions in the making rather than in hindsight (Saritas, 2013; c.f., Curry, 2015) to support policy-making (Miles, 2012).

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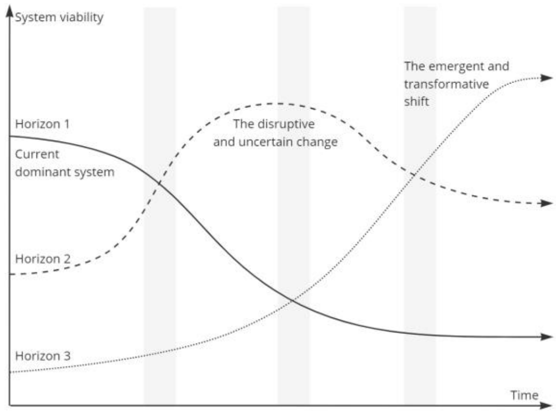

Figure 1 Three horiozons framework (Adapted from Hodgson & Midgley, 2014).

New systems become increasingly valuable, and the relevance of the predeceasing system decreases. The enclosed area in the middle of the graph (fig. 1) represents the triangle of choice (Curry & Hodgson, 2008), wherein the uncertainty of H2 represents a transition. Where strategies can either propone the third horizon or prop up the first (Curry, 2015) depending on the behavior of actors and their goals. Strategies and policy can thus be directed towards either of the systems (Curry & Hodgson, 2008), to sustain the status quo; pursue disruptive innovations; or seek transformative change, however, increasingly difficult yet valuable (Hodgson & Midgley, 2014). This framework allows the observer to examine the current and possible future systems and their relation to one another. Some horizons may lie dormant for ages, whereas others fade out of relevance and make way for new transformations and visions (Curry & Hodgson, 2008).

Research question & aim.

By utilizing a futures study approach, this paper aims to explore the notion of circularity in the energy sector and the future thereof, to reimagining a future energy system driven by circularity. Exploring the following research question:

What are future systems of circularity in the energy system?

2 Methodology

Foresight, and more specifically 3H, is used as a tool for theorizing about the development of energy and surrounding sectors (Piirainen & Gonzalez, 2015). Combining conceptual development with an empirical approach which addresses the lack thereof (Kirchherr and van Santen, 2019). To do so, this futures study applies a continuous horizon scan (Palomino et al., 2012), followed by three analytical phases, predictive, interpretative, and critical (Inayatullah, 2013) which are sequenced such that the output of one is the input of the other (Spaniol, & Rowland, 2022). To then explain these findings through the 3H framework to understand competing and synergetic systems of circularity in the energy sector. As such, the methodology is equally dynamic and non-linear as the system in question (Saritas, 2013), see fig 2. This approach is thus adapted to the context of the study (ibid), which is that there is an abundance of consultancy and agency reports whereas academic contributions are scarcer.

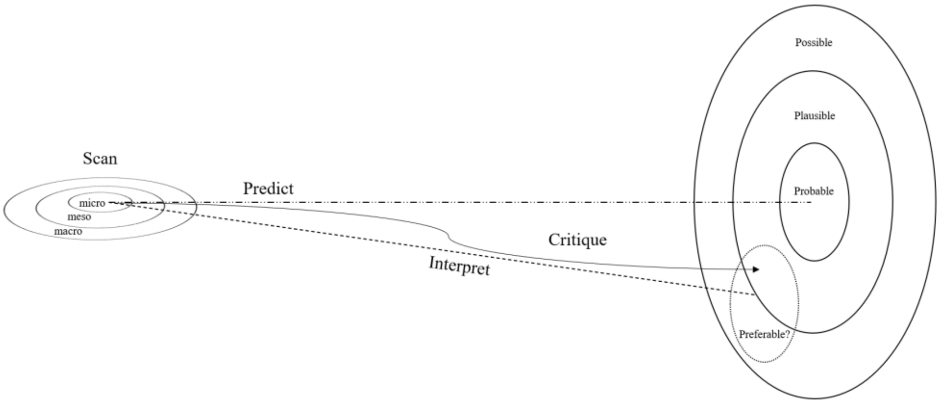

Figure 2 Visualization of research process. Showing the process of contrasting predictions with interpretations to understand the transition towards a envisioned state of a circular energy system.

Data collection

Data collection took the form of an environmental scan (Puglisi, 2001). Beginning in early January 2023 and transpired actively all throughout April. In total, an approximate of 100 online sources, 74 reports, and 62 scientific articles[1] have been recorded and subsequently reviewed. Sources pertained to the areas of politics, society, economics, technology, and environment, which all have bearing on the energy transition (Doh, Budhwar, & Wood, 2021; Sovacool, Hess, & Cantoni, 2021). Sources were then commented upon to collect initial thoughts and connections with other signals and insights. This process was primarily an individual effort; however, a diverse set of sources were scanned for signals. Sources include webinars, journals, media articles, podcasts, newsletters from leading organizations and interest groups, and latest outlooks from agencies both national and international (Puglisi, 2001). In part, scanning was a serendipitous endeavour, as sources would emerge through regular work, web-browsing, and interaction with colleagues and stakeholders in the energy field.

Analysis

Each gathered source, trend, and signal underwent an analysis consisting of three interrelated phases. The first analytical phase consists of extrapolating trends, future energy demand and production, the share of renewable energy and the need for storage.

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[1] Scopus search strings TITLE-ABS-KEY((“Energy sector” OR “Energy industry”) AND (circularity OR “circular economy”)); (Circular*, AND Energy); (“Energy loop” AND closing). Amongst many other more directed searches and snowballing.

Where available, such data was drawn from the sources which have conducted thorough works with a more specified focus. Providing a baseline of developments from which further analysis could be conducted and discussed. Outlooks from the international energy agencies as well as select national energy agencies were prioritized, which yielded numbers pertaining to future energy demand, production, and energy mix which then needed to be contrasted with each other to interpret and critically assess projections.

The interpretive stage of the analysis attempts to understand opposing views, trends and their countering forces (Inayatullah, 2013). It explored the consequences of developments and change, leaving questions for further discussion and insights towards the potential evolution of the system in question. Different elements of circularity were compared and conceptualized.

The final stage of the analytical process is applying a critical lens to these developments, problematizing what exists and what is considered the future by sources (Dator, 1995). By deconstructing different narratives to find underlying motivations and agendas that might affect their viewpoint. Considering who is proponent of certain developments and how they may benefit from certain developments (Inayatullah, 2013). Which is a crucial step when surveying grey literature as many pieces or writing originate from or are influenced by lobbying and interest groups. This was done by investigating actors and addressees of the reviewed text, to uncover both who authored the text and how, and who was the intended recipient of the manuscript. Wherever possible, snowballing was done to identify the source material, e.g., news articles disseminating research findings. Thereby, one layer of interpretation could be avoided.

Using the three horizons

Curry & Hodgson (2008) in their seminal piece introducing the 3H framework, exemplified their horizons using energy futures. We thereby continue this track and apply the 3Hs to the energy sector to explore futures of circularity. The elements of circularity differed in terms of occurrence. Together they formed a logical progression and supported an explanation of the systems' current state in conjunction with emergent trends and future transformations (Curry, 2015). This guided the understanding of contemporary systems and managed competing visions (Inayatullah, 2013; Hodgson & Midgley, 2014). The horizons were used as steppingstones, starting with circular management of material [H1] which gives rise to CBMs [H2], which in turn enable a more circular management of the flow of energy [H3]. This created a narrative through which the transition between these systems could be described. Each of these systems have been described using signals and trends identified in earlier stages of analysis. The latter horizon has been developed using weaker signals (Curry & Hodgson, 2008) and is thus a product of visioning, whereby the goal was to conceive what a circular energy system might entail given the identified trends and signals.

3 Results

Three perspectives permeate the discourse around circularity in the energy sector, dominated by flows of material (Mendoza et al., 2022), followed by a servitization of energy (Paukstadt & Becker, 2021), and signals of a circular energy system (see e.g., Janik, Ryszko, & Szafraniec, 2020; Deloitte, 2018). Together, these describe the current state of circularity in the energy sector and pave the way for future development. These themes are represented as their own system (Hodgson & Midgley, 2014) as visualized in fig 3:

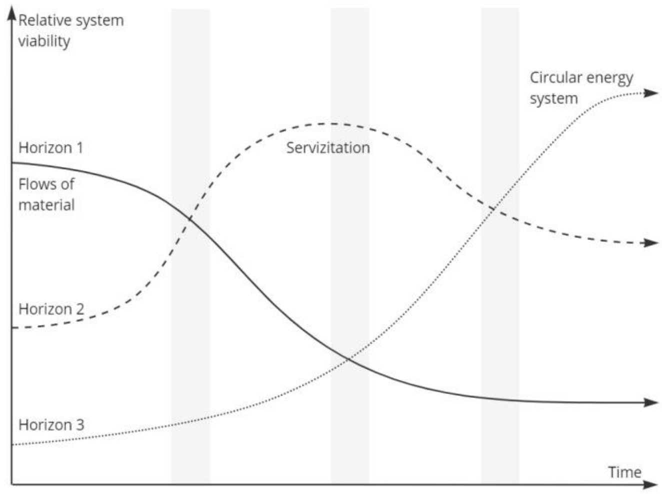

Figure 3 Three horiozons of circularity in the energy system (Adapted from Hodgson & Midgley, 2014).

First, establishing the dominant state of circularity in the energy sector (i.e., H1 – Flows of Material), to then lay out the identified trends and uncertainties following a servitization of energy (H2), towards a vision of a circular energy system design (H3).

Flows of Material - Horizon one

Primarily, mentions of circularity in the energy sector pertains to the circular management of the material of infrastructure, such as solar, wind and battery installations (EEA, 2021; EC 2022). Following the rising concerns as the first wave of solar panels will come offline in the coming decade. Stressing the issues with separability of wind turbine blades (Pennington, 2022) which will become a critical issue before the end of this decade (Mendoza et al., 2022). Closing the energy loop in this stream of discourse pertains to the cyclical flow of natural resources that are used for generating electricity e.g., wind and water (see, Zell-Ziegler et al., 2021).

Another movement herein, is that of second life. Which falls under the cycle principle, repurposing e.g., electric vehicle batteries for general storage, which extends the lifespan of batteries and materials thereof (Toorajipour, 2023). However, this has raised concerns regarding the availability of resources for new, higher quality batteries. As more material is now in circulation, and thus, less is available for remanufacturing (Heath et al., 2022). However, alternatives to recycling such as repurposing or remanufacturing have been shown to generate more environmental and economic value (ibid).

However, some materials have yet to find ample paths of circulation, wind turbine blades are notorious in this aspect, with their Fibre Reinforced Polymer composition

(Delaney et al., 2021). Instead, decommissioned turbine blades have been repurposed as wind shelters, bus stops and protection for bike parking, along with multiple concepts of other uses (see organizations Re-wind; Reblade). These approaches allow for the repurposing of materials and reducing waste, however, still demanding the extraction of virgin resources and manufacturing rather than remanufacturing. Furthermore, as longevity of these system components increase, their contribution to the systems overall sustainability decreases, yet, as more infrastructure is put in place, resource availability is put under pressure and therefore this system continues to be necessary. Moving forward, repurposing gas infrastructure for the use of green hydrogen (European Hydrogen Backbone [EHB], 2022), and upcycling pre-existing plants and upskilling their local workforces (Enel, 2016) to ensure a just transition which is socially sustainable (Lebré et al., 2020; Moody-Stuart, 2021).

Managing these product life cycles, have given rise to novel business models expressing the service dominant logic (Vargo & Lusch, 2007), such as energy-as-a-service and leasing, described below.

Servizitation – Horizon two

As-a-services in the energy sector are rapidly growing and the future thereof remains uncertain (Park, 2022). In Deloitte’s (2018) consultancy report for Finnish energy company, they highlighted Energy-as-a-Service as an area of great potential. Similar initiatives are identified in Sweden where the state owned Vattenfall AB has begun to assume responsibility over energy provision, including regulatory aspects and financing for clients (Vattenfall, n.d.a). Further examples of CMBs are leasing of energy installations such as Utilities-as-a-Service and Energy-savings-as-a-Service (ENGIE Impact, 2023); thus, enabling a circular management of products such as heat-pumps and solar panels through a product-as-service logic or establishing a take-back or buy-back system to secure the handling of materials (Rietveld et al., 2019). Additional emerging business models pertain to the management of system volatility, such as Demand Side Response services, and different types of Frequency Reserves and business models thereof (Mendoza et al., 2022), amongst a plethora of emerging business models. However, one great uncertainty is the proposed reform of the electricity market design (EC, 2023) which could have a great impact on these business models. Further changes occurring on the EU legislative and strategic landscape introduce uncertainties regarding the role of biomass in future energy systems; and the viable scale of hydrogen networks, which are poised to repurpose natural gas infrastructure (EHB, 2022). In effect, this transition will continue to be a turbulent phase, riddled with uncertainties to be navigated, and a lot of questions arise around the implications of Energy-as-a-Service.

On a micro level, a servitization of energy utilities lowers the bar for consumers to make green investments and makes for easier compliance (Vattenfall, n.d.b); meso, changes the role of utility companies (van Nuffel, 2018); and macro, changing the system level focus of the energy mix from international to interdistrict (Zakeri et al., 2022). Digital traceability of products is a key enabler for the CE (SITRA, 2021), and as such, similar initiatives are happening in the energy sector, allowing for the tracking of renewable energy through more granular energy certificates, ensuring 24/7 renewable energy, which in turn promotes the use of storage and flexibility (EnergyTag, 2022).

As systems become more decentralized, through e.g., microgrids, the role of traditional utility companies is changing, they are transitioning from being the focal actor to the back-up or facilitator, as users become prosumers and districts become largely independent (van Nuffel, 2018). The service logic introduces novel aspects into consideration of the energy supply chain, away from focusing on production to consider what service energy delivers (Complexity labs, n.d), such as light, heat, or computing rather than purely electricity or heating. Utility companies are beginning to show signs that they are coming to the realization that they need to become service-providers rather than sellers of Energy-as-a-Commodity. Once these companies claim this responsibility, their inclination will turn to the conservation of energy, as it being their primary resource, moving us into the third horizon.

Circular Energy System - Horizon three

Today, a large amount of energy is wasted, dispersed into its environment through exhausts, sewers, power lines and chimneys, to name a few (Weinem, Iversen, & Balcerek, 2019). Recapturing and repurposing said heat can go a long way towards reducing primary energy demand (ibid; Averfalk & Werner, 2017), and such projects are on the rise (International Energy Agency [IEA], 2022a). This system represents a scenario where Energy-as-a-Service and its value chain adheres to the circular principles. It does so, using weak signals of change as this mode lays latent in the current dominant system (Curry & Hodgson, 2008). However, many examples exist today, and these are hereinafter extrapolated to cover many more areas and applications. These current examples, on a micro-level, include anthropogenically heated passive houses, FTX systems recapturing waste heat; on a meso-level, district heating systems [DHS] which both circulates return heat and repurposes it for street heating (Circular Turku & City of Turku, 2021); and sector-coupling where waste heat is repurposed for heating elsewhere (see e.g., Parker & Kiessling, 2016). On a macro-level, the food system where energy is used to generate food and waste thereof is used to produce biofuels (Mishra et al., 2022). In a future system, we expect this to develop towards inter-building heating systems; increased heat recovery injected into DHS; and creating a green hydrogen economy.

It is thought that future DHS will not require as high operating temperature and can instead suffice with temperatures sustained from low-temperature waste energy sources. This has the synergetic effects of lowering heat loss and increasing the ratio of electricity generation of combined heat and power [CHP] plants (Weinem, Iversen, & Balcerek, 2019). This trend is in part driven by technological advancements and building efficiency improvements. Further accelerated by the changing role of biomass which is currently the primary fuel of many CHP plants in the Nordics. The demand for biomass is growing in the EU (Mandley et al., 2020), however, should be allocated towards heavy-duty industries such as material use, aviation, and shipping rather than electricity (Kircher, 2022; Material Economics, 2021; Brown et al., 2018). Supporting these industries' decarbonization in ways other than electrification. Currently, biomass is excluded from circularity metrics due to unknowns regarding the circularity of soil nutrients (Circle Economy, 2023) and should therefore take the steps necessary to enable a sustainable forestry industry where only solid residual biomass is used for cogeneration as it is with many CHP plants today.

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What is considered waste heat today, will be a precious resource of the future, used as an energy source which minimizes primary energy use. In this scenario, waste heat is recaptured from sources such as subways, server halls, and exothermic chemical processes to then be reused in DHS, food production, and regeneration. Underground electrical cables can be combined with DHS to create easier access to each and allow waste heat from the cables to contribute to the heating network. Which has the synergetic effects of allowing higher electrical loads and reducing electricity needs for active cooling (Davies et al., 2019). Intra-building heating systems can allow for heat reservoirs to follow shifting needs from e.g., between residential housing and office spaces over the course of the day. Similarly, heat energy can be shared between commercial facilities such as grocery stores and greenhouses (Mishra et al., 2022). In certain cases, waste-heat-to power can be a viable option, thus further closing the energy loop:

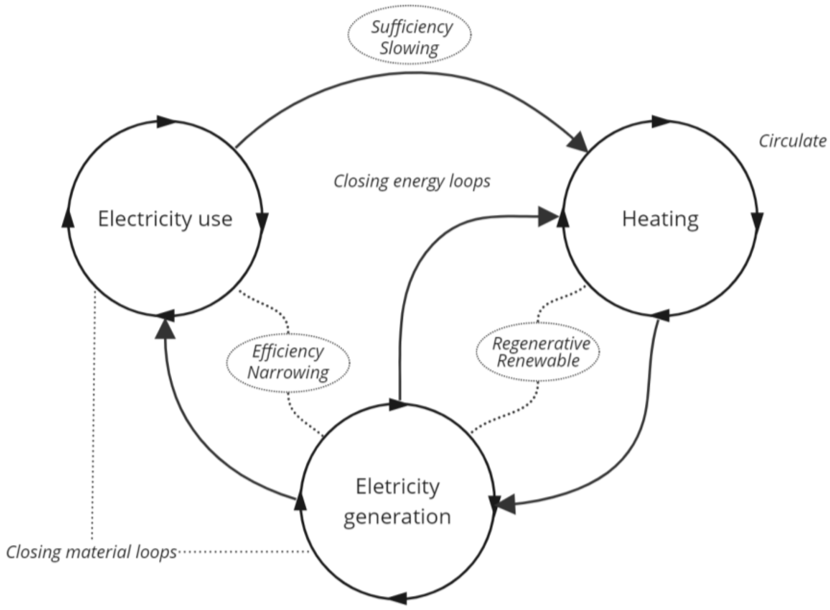

Figure 4 Flowchart of a future circular energy system.

In such a scenario, future energy demand can double without the need for doubling generation, through both industrial heat exchangers, and offsetting demand for where it is feasible. Transferring energy from sectors with excess heat to those in need of it, so that rather than doubling generation, energy is used twice; and instead, doubling down on strategies such as sufficiency (see e.g., négaWatt, 2017). An internet enabled, energy system will allow for the required tracking of flows and losses in the system, beyond the meter. It will allow for timely response and adjustment to match demand with production; and it will allow for monitoring metrics that pertain to the circularity of the energy system. Empowering users with insights, traceability, and choice. To then, introduce goals to minimize waste heat, for the benefit of society and environment by minimizing heat pollution and global warming (Zevenhoven & Beyene, 2011). Also aligning with pushes to question perpetual economic growth (Hickel et al., 2022; Zakeri et al., 2022). However, most outlooks today, project a steady growth of both energy and electricity needs globally (see e.g., IEA, 2022b McKinsey & Company, 2022) with emerging markets and developing economies at the helm. Advanced economies should see lowering demand for overall energy (IEA, 2022b), whilst their need for electricity increases (IEA, 2023) due to electrification of industry and transportation amongst others. However, economic projections of future demand lack consideration for structural change (Swedish Energy Agency, 2016), and assumed certainty can be a treacherous path and act as a mirage (Hogan, 2022). Critical assessment of reviewed reports, common in social media and journalism are traced back to lobbying organisations. These are not inherently incorrect, but they follow a common theme and agenda, adhering to the system of old and projecting therefrom given the electrification of industry and transport sectors (see e.g., Energiföretagen 2023).

4 Discussion

Three horizons (H1-H3) depicted above, show three possible future systems (Hodgson & Midgley, 2014). To understand how the CE principles and strategies work together with the energy transition, we contrast possible change strategies with the presented systems. Interventions can thus be directed towards enforcing the status quo or set a path to a more sustainable future (Curry, 2015). Continuing at H1, solely considering the material management of installations, is the first step towards circularity within the energy sector. As shown, servizitation in the energy sector can either bolster H1 by laying a value adding service system on top of the energy-as-product logic (see, Park, 2022), or guide the path towards a service logic which can support closing the energy loop. Combined, these systems work towards increasing the level of circularity in the energy sector. Described as horizons, these systems of circularity correlate with the strategies of both the circular (Bocken, et al., 2016) and energy transition (Zell-Ziegler, et al., 2021) by utilizing 100% *renewable* energy sources for virgin energy that *regenerate* rather than polluting; *narrowing* the need for energy by increasing *efficiency* and designing and nudging for *sufficiency*, *slowing* the need for more; *cycling* by reusing energy for multiple purposes rather than discarding it as waste heat, thus increasing *efficiency* further; and finally, closing the larger loop by first repurposing and then regenerating excess heat back into useful and valuable energy, thus, *slowing* the need for virgin energy and closing the energy loop. The circular principles thereby correspond with the energy transition strategies, however, with the novel addition of *cycle* (see fig 4), which has been found to be largely lacking in the energy transition discourse. Thereby, adding the notion of *cycling* in the energy system can provide synergetic effects of supporting both transitions. Questioning whether this constitutes a complete system transformation (Curry, 2015), we would argue that given the current state of DHS (Averfalk & Werner, 2017) and market incentives, that the changes underlying H3 constitutes a transformation of the energy system. Gone from endless consumption (Curry & Hodgson, 2008), towards regenerative models. We have thus moved one horizon forward (c.f., ibid), about the enter the turbulent times, and the weak signals from the beginning of the millennia are maturing. We are thus about to enter the triangle of choice, which allows us to consider in a timely manner the strategies we adhere to, policies we design, and our values (ibid).

5 Conclusions

This futures study, identifies possible avenues for the proliferation of circularity in the energy sector, providing initial insights towards how servitization may affect future business models in the energy sector (Park, 2022). Combining conceptual development with an empirical approach (Kirchherr and van Santen, 2019). Positing that servititization in the energy sector can, depending on strategies and policy, create a value adding product-service system or facilitate an energy as a service logic which transcends the energy system into a more circular one. This view (H3), goes beyond the traditional views on circularity in the energy sector, contributing to theory with a broader scope on circularity in the energy sector than previous research (see, Mendoza et al., 2022). Explicating the broad application of circularity in the context of an energy system and extending the notion of circularity from focusing on material management. Showing how energy can be cycled and used more efficiently in future systems, and how such a movement can be bolstered by fostering a servitization of energy. The energy transition can and should both enact and enable the circular transition. As such, the energy system can be included in circularity goals and plans, following the prime example of Turku (Circular Turku & City of Turku, 2021). This study thereby contributes to theory and practise by integrating distinct developments into a viewpoint of how they can come together to form a more sustainable energy system. Continued alignment of these strategies enables synergetic development and points toward areas in need of further work, discussion, and research to support the design of a circular energy system; where waste heat is regarded as a resource to be captured and used, rather than it pollute its environment (Zevenhoven & Beyene, 2011). That rather than following scenarios of perpetual growth, consider low-energy scenarios as a viable alternative given these synergetic strategies.

Policy recommendations

Given these evolving trends, we lay forth the following recommendations to support H3 based on insights generated from this study. Recommendations differ depending on level, micro-level advancements can generally be attributed to efficiency improvements. Therefore, we focus henceforth on the levels of meso and macro. Meso-level implications concerns municipalities and regions, in the planning of power and heating networks. Future development and refurbishment of DHS networks should consider low temperature solutions (see, Averfalk & Werner, 2017). The EU’s new taxation of biofuels should be seen as a push in this direction to seek out other sources of energy, such as capturing waste heat from industry, commercial, and residential sectors. DHS will be a foundation of a circular energy system for both heating and cooling.

On a macro-level, going forward with the investigations of EU energy market reform, the implications of servitization need to be further investigated. To support business models where lowered consumption is fostered, and implementing targets that consider energy waste. Furthermore, resource availability and a socially sustainable transition needs to be considered. Requiring assessment of decommissioning´s impact on local communities and possibilities for upcycling and upskilling. Furthermore, Lebré et al., (2020) raise the concern that future scenarios rarely acknowledge social sustainability regarding resources required for energy transitions. Therefore, we extend this concern to also consider future resource availability for developing nations. Today, wind and solar power are becoming cheaper than fossil alternatives, however, in a future of resource scarcity this situation might reverse. Whereby developed nations will have established their renewable needs and developing nations are left behind.

Future(s) research and limitations

This study has presented several avenues and areas in need of further research, considering both theory and further inquiry for policy creation. Necessary simplifications have been made to work with the energy system (Curry, 2015). Further work is required to increase conceptual clarity of circularity in the energy sector, to e.g., distinguish between recover, reuse, and recapturing of energy; and translating efficiency improvements into metrics of circularity. There is further potential to extend the framework of Mendoza et al (2022) to go beyond wind and material to apply more broader to circularity in the energy sector.

There are several limitations to this study. To start, data and had a strong bias towards Nordic and EU sources. Although prominent areas for the development of both the circular and renewable transition, further insights can be generated by a broader scanning followed deeper inquiries (Palomino et al., 2012). It is also likely that several examples of circularity in the energy sector have been overlooked if they do not use the keywords thereof. Therefore, a more rigorous scanning process should search for generic cases and try to evaluate their relevance for circularity. Similarly, this study has been dominated by the perspective of one and could benefit from participatory exercises. This study has also had quite an opportunistic focus, which can fail to account for be downsides to these suggestions, and further sector coupling affecting resilience. Futures studies is not an objective inquiry but can provide alternative paths for development and insights into current trajectory, possibilities, and threats. We have deliberatively refrained from explicating boundaries in time as to not imply any predictions.

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Data

All reviewed data has not been referenced in this study but have ultimately affected the interpretations of the author to varying degrees. Therefore, in the spirit of openness and transparency, all recorded pieces of data for which it is possible, are available upon request.

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