Circular economy principles in the context of energy transition

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Abstract

Decarbonising the power system holds a critical role in mitigating climate change effects. Entrepreneurs contribute to this transition through circular business models. This paper aims at investigating entrepreneurial circular economy principles. A set of principles for adopting a circular economy perspective on business model activities in the energy sector is suggested.

Key words

Circular economy, business model, energy start-up

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Introduction

Energy transition aims at reducing energy intensity and fast decarbonisation of the energy system by promoting renewable energy, energy efficiency and sufficiency. Business Models (BM)s increasingly act as essential drivers for this low-carbon transition (Wainstein and Bumpus, 2016). Circular Economy (CE) refers to strategies and principles aiming to optimize the use resources, both energy and material, by eliminating waste in the production of goods and services. Recently, many companies started to notice that adopting CE principles could mitigate risks associated with resource prices and supply disruptions. BM concept acts as a useful tool to gain competitive advantages (Lecocq et al., 2006), support practitioners and facilitate business process transformation (Ahokangas and Myllykoski, 2014). Therefore, BM can align innovation and CE towards more circular business activities (Guldmann et al., 2019). Research on BM to implement circular principles has grown rapidly in the last five years (Diaz Lopez et al., 2019). CE principles for the design, implementation and evaluation of a sustainable systems go beyond the technological solution (Velenturf and Purnell, 2021).

In this context, CE principles can guide and enable renewable energy transition and uptake (Chen and Kim, 2019; Mutezo and Mulopo, 2021). The paper contributes to this field of research and exploring the CE principles that support energy transition. To achieve this goal, the authors explore starts-ups of the energy transition field and investigate their BM.

This research draws on a framework that consists of five circular strategies: narrow, close, slow, regenerate and inform (Konietzko et al., 2020). Narrowing strategy or resource efficiency aims at reducing the used energy and material during design, production, distribution, use, delivery and recovery. For example, to incentive customers to consume less energy. Slowing strategy is centred around prolonged use and reuse of energy and material over time. Remanufacturing and repair. Designing reusable packaging or durable products are activities that end in a slowdown of the resources' flow (Bocken et al., 2016). Closing strategy is about creating the missing link between post-consumer waste and production. Reintegrating products into the system when they reach the end-of-life results in circular flow of resources and design out negative externalities (Mishra et al., 2018; Niero and Olsen, 2016). Regenerating strategy involves business activities that return degraded or damaged sites to a state of acceptable ecosystem health, using renewable energy and materials as well as transforming unwanted material into a new useful material (Morseletto, 2020).

Informing strategy refers to practices that use information technology, such as business analytics and digital technology, to support circular BMs. For instance, connected products, which inform valuable data, can slow material flow by informing maintenance and repair needs (Zaoual and Lecocq, 2018). This paper suggests a set of CE principles that provide a guideline for adopting a circular economy perspective on BM activities in the energy sector and support decision-making processes.

Approach

To identify suitable cases, a deep search was conducted in the network of InnoEnergy organisation, which is a European organisation that supports start-ups contributing to energy transition. Two authors independently screened the start-ups' network for circularity strategies. If one or more strategy were found in the value proposition, the case would be included. Following purposive sampling method, 27 start-ups were selected. The value propositions were subsequently analysed in detail to examine whether they belong to one or more CE strategies and to identify the respective principles derived from the BMs.

Following multiple case study approach, qualitative data were collected from multiple sources (Eisenhardt, 1989) to triangulate our data and add facts to our cases. First, the main source of information about the value proposition was the InnoEnergy and the start-ups' websites. Second, data from sixteen interviews about the BM aspects has been also revised. The interviews included detailed questions regarding value proposition, sustainability aspects, opportunity identification, value creation and economic models. Third, data from external sources (article, videos, etc.) was examined. However, due to their novelty there was quite limited third-party material on few start-ups. In sum, an extensive data from multiple sources and perspectives on each start-up case was obtained.

A qualitative content analysis is used to examine the data. All written material was coded and evaluated using qualitative content analysis method described by Mayring, (2004). Deductive codes were applied (Strauss, 1987) starting with a given set of analytical categories from the framework of CE strategies as introduced above. Two authors independently match any gathered information to the respective categories in the framework. Differences in opinion and perspectives between the authors were discussed until an agreement was reached.

Key insights

By analysing a range of value propositions provided by start-up business cases in the proposed CE framework, the paper highlights insight into CE principles in the context of energy transition Table 1.

Close energy waste

The closing strategy includes business cases creating value from wasted heat from industrial and commercial processes. This quantity of energy that is not put to practical use can be recovered by numerous methods: it can be reused within the same process or transferred to another process. Industrial heat waste is estimated between 20 to 50% of industrial energy consumption (Johnson et al., 2008). Applying the principle **Use waste heat to create new products and services** firms use the waste heat of the customer to create value and avoid negative externalities. The C.1 offers self-powered sensors for industrial energy monitoring that captures waste heat from hot surfaces and generates electricity to feed itself. In the **Use waste heat to extend the business model**, firms exploit waste heat in adding activities or expanding the core processes of the existing BM. The C.2 extends the core activities of its BM which is basically a data centre service provider to be later an energy service provider. The data centre is divided into small units that can be installed on the premises of energy consumers. Each unit has two functions: computing units and energy boiler.

Waste to energy

Eliminating waste from the industrial chain by reusing materials as a source of energy allows production cost savings and less resource dependence. **Build bio-waste-to-energy local loops** principle is a process to convert the local bio-based waste (e.g. industrial, agricultural, residential waste) into a form of bio-based fuel (e.g. bio-gas, bio-fuel, bio-char) , which can be used for heating supplies of a district (Pan et al., 2015). C.3 converts local forestry waste into a biomass product made of renewable substances of recycled wood waste. The value proposition is a clean-burning and cost-effective heating fuel, alternative to fossil fuel heating systems.

Some types of waste are dangerous and contaminating, the **Turn harmful waste into energy fuel** principle is about mitigating the effect of waste on society by turning waste into energy. Wastewater treatment plants discharge sewage with residue sludge that contains micropollutants and micro contaminants. Resource recovery from this waste holds new business opportunities (Puyol et al., 2017). C.4 turns harmful sludge into homogenous biofuel with a high energy density for power production of CHP plant.

Storage systems are mostly costly to be commercialised. One way to reduce this cost is by using available waste material to build new storage systems. **Create battery systems from waste materials** is about using waste material of one industry to build a heat storage system. The increased need for energy flexibility inspired C.5 to create a thermal energy storage solution that captures and stores the output of heat intensive industries to be reused later. This battery is made from refractory ceramics from industrial waste.

Inform consumption

Informing principles create value from capturing, integrating, and visualising new information about consumption. **Locate unnecessary consumption** describes unnecessary consumption detected along the industrial or commercial processes. In the cases C.6 and C.7 a system of sensors distributed along the manufacturing process capture data from each part, integrate it with external data (e.g. weather forecast), process this data and visualise it to support the decision process of the user. Customers can compare real-time consumption with the reference model to detect deviations. C.8 promotes the ”Digital hotel”, a hotel with wireless thermostats, connecting appliances and equipment and automating processes. The implemented software captures any unnecessary consumption such as detecting open windows, temperature at night, forgotten heating ON in the bathroom, etc. In the principle **Manage energy consumption with cross-domain data** firms capture data that are previously inaccessible or unmeasured (electricity price, weather forecast, building thermal storage, etc.) to optimise energy consumption. For example, C.9 added, besides temperature, variables such as wind speed and direction, solar radiation, rain, snow clouds and fog, energy price and available energy source to the building management system. Swimming pools bear an energy optimisation opportunity for C.10. Besides energy consumption several factors are measured, such as occupation, air humidity, water and air temperature. C.11 adds value to wood drying BM by providing real-time supplementary data (air velocity, temperature humidity, and energy price). As a result, the process is transformed from being static to a more dynamic one that responds to measured factors and increases energy efficiency.

Renewable energy

Renewable energy is associated with a regenerating strategy in which business is powered by renewable energy. The proposed principles support renewable energy take-in by overcoming one or more Renewable Energy Sources (RES) barriers: high payback period, social acceptance, difficult installation and high initial cost. In the principle **Increase renewables productivity** firms seek to augment the productivity of RES to reduce its payback period, for example, C.12 designs hybrid PV solar panel that produces both heat and electricity simultaneously. In the principle **Design renewables with less occupation space**, C.13 provides hybrid solar panel with less occupation space (up to 40% less space) reducing space requirement and accessing new market niches. The separation of house design and PV solar panel design has an influence on RES social acceptance. The principle **Design aesthetic renewables** aims to design integrative RES. C.14 offers a roofing solution that generates photovoltaic electricity and replaces the conventional roof with a homogeneous look. **Design renewables for ease of installation** is a principle with the objective of reducing RES cost by eliminating the cost of installation. By adopting do-it-yourself in the PV solar panel, C.15 encourages customers to install the system by themselves and have a competitive cost. To overcome one of the major barriers, the high upfront cost, C.16 offers PV solar panel systems as a service. The start-up created this synergy between collecting funds by people through a crowdfunding platform and energy-as-a-service through third-party ownership of RES. The BM creates an attractive investment opportunity for private investors as well as low cost energy for consumers. In the **Energy as a service** principle, the provider maintains the ownership of the PV solar panel system installed on the customer property and sells kWh of renewable energy, usually in long-period contract.

The principle **Increase renewables durability** is a slowing strategy that aims to maintain a good performance of RES over time. PV solar panels that were installed for more than 8 years might have a potential progressive degradation of performance, which leads to production losses. C.17 developed algorithms based on a self-learning system to establish a reliable diagnosis of the weaknesses inherent in photovoltaic installations. The proposed solution allows PV solar plants to increase production, thus their revenue.

Raising awareness and design interventions to influence and change consumer's behaviour is an essential mechanism to overcome social acceptance. Providing information to guide consumption choices is fundamentally important (Testa et al., 2020). C.18 uses the principle **Use gamification to**

promote renewables and proposes renewable energy-based games to engage and educate about the importance of renewable energy and footprint impact. The Hybrid Energy Floor is a game in which the floor converts kinetic and solar power to electricity, which is used to power educational energy games.

Electric vehicle

Electromobility is one of the major innovations that will be indispensable in the coming years in the mobility, energy and automotive industries. However, the arbitrary charging of EVs can cause grid overload which leads to huge damage for national grids, charging station and property owner. **Limit grid overload** contributes to provide solutions that distribute load among charging EVs smartly. The charging App of C.19 takes into consideration several data sources: first the property owner's need and past behavioural patterns, the charging station and electricity prices, and grid overload. The production of EV batteries contains scarce materials such as rare earth elements. Minimizing extraction of these materials is an important strategy to keep the environmental impact low (Romare and Dahllöf, 2017). Second-life EV batteries hold business opportunities all along the value chain: selling the used battery, battery refurbishing, second life in other applications, and recycling of material (Olsson et al., 2018). **Reuse EV batteries in new application** refers to creating new value from discarded EV batteries. C.20 exploits the remaining 70-80% storage capacity for other purposes less demanding, such as storing the surplus renewable energy.

The **Design batteries with non-toxic material** principle associated with regenerative strategy is focusing on toxic or scarce material from energy storage systems. For example, C.21 developed a battery that is made of abundant, available usable material and C.22 designed batteries out of nickel, cobalt and lithium.

The **Establish infrastructure for green mobility** principle is associated with building supporting infrastructure for green mobility. C.23 built a refuelling station for hydrogen vehicles targeting cities, rural and touristic areas where a small station network is required. One of the disadvantages of having an EV is its limited range. The **Design modular solutions** principle is about designing modular solutions to reduce the environmental impact. An affordable EV cannot satisfy occasional peak range requirement. However, the frequency of long distances is low. C.24 offers a range extending service for electric vehicles. The start-up proposes a modular solution, a range extender that can be dis & attached to the EV. Drivers can rent the range extenders for long distance trips and change it every 50 km. Modularity solutions are based on system component interchangeability, when components are capable to serve the technical or production functions independently (Rajput and Singh, 2019).

Power grid

The penetration of EVs and RES makes the management of the distribution and transmission grid a complex process. Distribution System Operators who are responsible for distribution network reliability have limited visibility of the overload capacity in part of the grid which can increase the maintenance and upgrade costs. In the **build a connected grid** principle, monitoring is installed to send data about the load capacity of the different parts of the network to reduce maintenance and damage costs. C.25 provides a monitoring system based on sensors and a platform that gathers data about load capacity and provides information about electricity flows. This solution allows more RES to be integrated into the grid given the extant infrastructure. For the same purpose but in the transmission grid, C.26 designed an energy autonomous monitoring system tailored to transmission grid lines. The system uses the residual ambient energy present in the surrounding environment such as the electromagnetic field associated with current-carrying cables.

The **Virtualise energy flow** principle is about delivering information virtually, thus reduces the need for sensors, cables and batteries. C.27 offers a software-based solution that can mode the present state of every transmission asset. The real-time monitoring and predictive diagnosis do not require nor sensors, neither hardware and can reduce operational losses up to 25%.

Table 1 Entrepreneurial Circular Economy principles in the context of energy transition

Strategy	Case	Circular principles
Close	C.1	Use waste heat to create new products and services
Close	C.2	Use waste heat to extend the business model
Close	C.3	Build bio-waste-to-energy local loops
Close	C.4	Turn harmful waste into energy fuel
Close	C.5	Create battery systems from waste materials
Inform	C.6, C.7, C.8	Locate unnecessary consumption
Inform	C.9, C.10, C.11	Manage energy consumption with cross-domain data

Regenerate	C.12	Increase renewables productivity
Narrow	C.13	Design renewables with less occupation space
Regenerate	C.14	Design aesthetic renewables
Regenerate	C.15	Design renewables for ease of installation
Regenerate	C.16	Energy as a service
Slow	C.17	Increase renewables durability
Inform	C.18	Use gamification to promote renewables
Slow	C.19	Limit grid overload
Close	C.20, C.21	Reuse EV batteries in new application
Regenerate	C.22	Design batteries with non-toxic material
Regenerate	C.23	Establish infrastructure for green mobility
Slow	C.24	Design modular solutions
Inform	C.25, C.26	Build a connected grid
Narrow	C.27	Virtualise energy flow

Conclusions

This paper presents a set of CE principles in the context of energy transition. These principles are enablers for power system decarbonisation and guidelines to support decision-makers, power system actors and entrepreneurial thought and action.

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