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Circular Economy & Industry in 2035

Economic models and business models in industry

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The key factor “Economic Models and Business Models in Industry” examines the relationship between economic models, understood in terms of economic structures and market dynamics, and the business models of industrial companies. This variable analyzes and synthesizes the evolution of this relationship, explores its past and present developments, and analyzes and interprets future insights that help identify the various elements associated with this variable, thereby highlighting alternative pathways for its development.

1. Definitions

1.1. Defining the report topic

Economic models

The term “economic model” is used to refer to different things. In a general sense, economic models are theoretical frameworks designed to understand, predict, and analyze the behavior and dynamics of economic systems. In Thakur’s (2011) article, economic models refer to the methods and approaches used to study structural changes within economies. These include input–output analysis, the Leontief model, and methodologies for identifying the fundamental economic structure (FES).

More broadly, an economic model is a simplified representation of economic processes. It is a theoretical construct that represents economic procedures using a set of variables in logical and/or quantitative relationships. Economic models are used to explain economic processes and systems, such as capitalist, social, or mixed systems; predict economic phenomena; assist in formulating economic policies; and understand how economies function. They can range from simple theoretical constructs to complex mathematical models that simulate economic activities.[1]

Alongside this understanding of economic models, we also hear about linear and circular economic models. These are better understood as models of socioeconomic systems with two distinct patterns of behavior and relationships among system elements, including industrial companies, suppliers, and consumers.[2] These systems can be analyzed from macroeconomic, microeconomic, mesoeconomic, and metaeconomic perspectives, encompassing both economic structures and market dynamics.[3]

Economic structures

An economic structure represents the composition of and interaction among the different components of macroeconomic aggregates, including their relative changes over time and their relationship to the circular flow of income. Economic structure evolves as economies move from agriculture to industrialization and then to service-based economies. This structure encompasses interindustry relationships, marking a shift from primary-sector activities toward more complex interactions between the secondary and tertiary sectors as development progresses (Thakur, 2011).

[1] https://en.wikipedia.org/wiki/Economic_model

[2] https://www.eib.org/fr/stories/linear-economy-recycling

[3] https://www.project-syndicate.org/commentary/new-thinking-in-economics-by-andrew-sheng-and-geng-xiao/french

Market dynamics

Market dynamics refers to the changes and forces that affect markets and businesses, such as shifts in supply and demand, technological advances, and changes in consumer preferences. These dynamics can influence prices, competition, and the overall environment in which businesses operate.[4]

Business models

A business model is the design or architecture of value creation, delivery, and capture. This definition emphasizes meeting customers' unmet needs, specifying the technology and organization required to meet them, and capturing value from these activities (Teece, 2010). The definition was subsequently enriched by emphasizing the logic of creating and delivering value to customers. The key is to balance value creation, delivery, and capture to ensure the model's longevity, particularly in profit-oriented businesses (Teece & Linden, 2017).

1.2. Relevance to the study and links among the concepts

For this variable, we address the concept of economic models from the second perspective, including economic structures and the dynamics of relationships among actors within an industry. We therefore examine economic models and their evolution in the industrial sector, as well as their relationship to business models.

Industrial economic models: From linear to circular

The industrial sector is familiar with the linear economic model, which the circular economic model has sought to replace for forty years (Lanoie & Normandin, 2015). The shift from a linear to a circular economic model has been observed to bring changes and even tensions with existing business models, particularly when a company moves toward a more service-oriented economic model. Adopting a service-centered economic model entails fundamental changes in how the company is organized, how value is created, and how that value is converted into cash flows. These changes require new types of relationships between producers and customers, characterized by close cooperation, making it necessary to adapt or redefine the existing business model. The distinctions and interdependencies between economic models and business models highlight the crucial importance of considering both aspects carefully when moving toward new economic paradigms. Businesses need to rethink not only how they create value but also how they monetize it in response to structural changes and sustainable development challenges (Demissy & Le Dilosquer, n.d.).

The shift toward a circular and collaborative economic model in industry involves a fundamental reassessment of traditional business models. This change goes beyond modifying production processes or reducing waste; it also concerns how companies create, deliver, and capture value. It requires innovative thinking about resource use, product design, sustainability, and the development of closer, more transparent relationships with customers and suppliers.

In a circular economy, business models tend toward greater flexibility, incorporating services such as rental, repair, refurbishment, and recycling rather than simply selling products. This involves a shift toward meeting customer needs in ways that promote the efficient and regenerative use of resources.

Ecodesign, LCA, and recycling

Another concept associated with the circular economy is *éco-conception*, often also called *ecodesign*. Ecodesign is an approach that aims to minimize products' environmental impacts throughout their life cycles

[4] https://fastercapital.com/fr/contenu/Comprendre-la-dynamique-du-marche---un-element-cle-de-l-analyse-du-marche.html#:~:text=des%20d%C3%A9cisions%20%C3%A9clair%C3%A9es.-,La%20dynamique%20du%20march%C3%A9%20fait%20r%C3%A9f%C3%A9rence%20aux%20forces%20et%20aux,consommateurs%20et%20les%20influences%20externes.

by integrating environmental considerations from the design stage onward.[5] It is therefore fundamental to the circular economy transition because it enables the design of products that are easier to repair, reuse, recycle, or degrade, helping close material and resource loops. This promotes efficient resource use, reduces waste generation, and lowers energy consumption, aligning production practices with circular economy principles.

The terms *éco-conception* and *ecodesign* are often used interchangeably, although the former is more commonly used in Europe and the latter in international contexts. Both concepts involve integrating environmental concerns throughout a product's life cycle, but *ecodesign* may sometimes be perceived as having a broader connotation, including design and innovation for sustainability.[6]

In connection with *éco-conception* and *ecodesign*, we also hear about life cycle assessment (LCA), a key ecodesign tool. It quantitatively assesses products' environmental impacts at every stage of their life cycles, helping identify opportunities to reduce their ecological footprints. LCA is widely recognized and used in international standards such as ISO 14040 and ISO 14044.[7]

Recycling is the process of converting waste into new materials or objects. It is an essential component of the circular economy because it allows materials to be reused instead of extracted anew, thereby reducing the environmental impacts associated with producing new materials. Ecodesign promotes recycling by making materials easy to disassemble and separate at the end of a product's life, facilitating their recycling. By assessing environmental impacts at each life cycle stage, LCA helps identify stages where recycling can be improved to reduce the ecological footprint further. This creates a direct link among ecodesign, recycling, and LCA, reinforcing circular economy principles (Collard, 2020).

Historically, life cycle assessment and ecodesign emerged in public and academic discourse mainly from the 1970s onward, with formal standardization beginning through the publication of specific standards in the 1990s and 2000s. ISO/TR 14062, published in 2002, is often cited as an official definition of ecodesign.[8]

1.3. Key questions for the future

1. Innovation and product design—How can companies incorporate innovation and ecodesign into their products to facilitate repairability, refurbishment, and recycling while remaining competitive?

2. Consumption models—What emerging consumption models support the circular economy, and how can companies adapt to these new consumer needs and preferences?

3. Collaboration and partnerships—How can strategic partnerships among companies, suppliers, and recyclers be optimized to create effective circular value chains?

4. Technology and digitalization—What role will technology and digitalization play in tracking, managing, and optimizing circular resource flows?

5. Policies and regulations—How might changes in policies and regulations affect the evolution of circular business models, and what strategies must companies adopt to remain compliant?

6. Resilience and adaptability—To what extent can circular business models improve companies' resilience and adaptability in the face of future crises, including environmental crises?

7. Performance evaluation—Which key performance indicators (KPIs) are relevant for assessing the effectiveness of circular business models beyond traditional financial measures?

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[5] L'éco-conception des produits une démarche aux multiples avantages ! (trustt.io)

[6] L'éco-conception, c'est quoi ? Définition de l'éco-conception (réglementation et exemple) (youmatter.world)

[7] https://lesjoyeuxrecycleurs.com/lexique/eco-conception/

[8] L'éco-conception, c'est quoi ? Définition de l'éco-conception (réglementation et exemple) (youmatter.world)

2. Retrospective analysis

2.1. General past developments

The linear model as the foundation of industrial development

The linear economic model, characterized by its "take–make–dispose" approach, has been the foundation of global industrial and economic development, particularly since the Industrial Revolution.[9] This model relies on extracting natural resources to produce goods that are disposed of as waste once their life cycles end.[10] Although it has enabled rapid economic growth, it has several major drawbacks, primarily related to environmental sustainability and resource management.

The linear model has encouraged a culture of mass consumption in which increased product consumption is seen as beneficial to the economy. This culture manifests itself in the overproduction of goods and strategies designed to make products appealing to the public, leading to excessive acquisition of essential and nonessential goods. This model has also generated massive quantities of waste because of a narrow consumption mindset and the promotion of overconsumption without considering recycling or reuse opportunities.[11]

Waste: A history linked to the evolution of societies

The evolution of the concept of waste is closely linked to the evolution of human societies and their consumption patterns. In preindustrial societies, most materials were natural and biodegradable and could be reused or returned to the earth without causing significant pollution. Waste as we understand it today was virtually nonexistent in these contexts.

The advent of the industrial era marked a turning point in goods production and waste management. Mass production and the introduction of synthetic materials led to a substantial increase in waste generation. These materials, often nonbiodegradable, posed new waste management challenges, causing environmental problems such as soil, water, and air pollution.

The thirty-year postwar boom, characterized by rapid economic growth in many Western countries after World War II, further exacerbated the waste problem. Mass consumption and the adoption of disposable lifestyles led to an unprecedented increase in the amount of waste produced, often exceeding societies' ability to manage it effectively.

Toward the end of this postwar boom, awareness of the environmental impacts of inadequate waste management began to emerge. The challenges posed by accumulating waste highlighted the need for more sustainable management strategies, such as recycling, reuse, and reduction at the source.

This historical evolution laid the groundwork for adopting principles such as extended producer responsibility (EPR) and the circular economy, which aim to reduce the environmental impact of waste and promote more sustainable resource management (Micheaux, 2020a).

Recycling

The concept of recycling as we know it today began to take shape during the twentieth century, although its roots extend much further back. Modern recycling efforts became more structured during World War II, when materials were scarce and economies needed to maximize the use of available resources. During World War II, recycling initiatives were particularly driven by wartime needs, with materials such as metal, paper, and rubber collected to support the war effort. For example, governments encouraged citizens to participate

[9] https://www.youtube.com/watch?v=Oz5v5T5B8f4

[10] What is the linear economy? (ellenmacarthurfoundation.org)

[11] Linear Economy: Characteristics and Criticism - Profolus

in collections of scrap metal and other reusable materials to support military equipment production. Propaganda posters and national campaigns called on people to “save metal, paper, and fats” as a patriotic duty.[12]

However, it was in the 1970s, with growing environmental concerns and the first Earth Day in 1970, that recycling became commonplace in many developed countries. In the 1970s, the modern recycling movement took shape in response to growing environmental awareness, symbolized by the first Earth Day in 1970. This period saw the introduction of separate household waste collection in several cities, encouraged by public policies and community initiatives. Municipal recycling programs began to spread, allowing consumers to sort recyclable waste at home, which was new at the time.[13]

During the 1990s and 2000s, many countries strengthened their recycling programs and introduced strict legislation to encourage or even mandate recycling and proper waste management. In 1991, California adopted the California Integrated Waste Management Act, which required each municipality to reduce waste sent to landfills by 50% by 2000.[14] Founded in 1978, the National Recycling Coalition[15] expanded considerably in the 1990s, offering more educational programs and support for recycling initiatives at the local and national levels. In Europe, the EU adopted the Packaging and Packaging Waste Directive in 1994, requiring member states to recover and recycle a specified amount of packaging materials.[16] In the early 1990s, Germany’s Duales System Deutschland (DSD) established a company-funded recycling system for consumer packaging.[17]

2.2. Past developments in industry

The emergence of the linear model in the wake of the Industrial Revolution

Linked to and designed for the industrial sector, the linear economy model has dominated France and Europe since the Industrial Revolution. Extractive and manufacturing industries benefited from subsidies and tax incentives to stimulate production and growth (FONDS MONÉTAIRE INTERNATIONAL Régimes Fiscaux Des Industries Extractives : Conception et Application, n.d.).

In France, energy policy long favored fossil fuels such as coal and oil, subsidizing their extraction and use.[18] Easy access to inexpensive raw materials such as coal, oil, and minerals enabled low-cost mass production. The linear model was intrinsically linked to economic growth. Rising production and consumption were regarded as signs of progress and prosperity. Planned obsolescence, the practice of designing products with limited life spans, was encouraged by some manufacturers to stimulate consumption.[19]

Negative externalities such as pollution and resource depletion were ignored or underestimated (Lanoie & Normandin, 2015). Infrastructure such as roads, ports, and pipelines was built to facilitate the extraction, transportation, and consumption of natural resources.

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[12] https://www.nationalww2museum.org/war/articles/salvage-for-victory-world-war-ii

[13] https://www.linares-recyclage.com/lhistoire-du-recyclage/#:~:text=En%201970%20le%20sigle%20du,conscience%20collective%20du%20probl%C3%A8me%20environnemental.

[14] https://riversideca.gov/publicworks/trash-recycling/california-integrated-waste-management-act-ab-939

[15] https://nrcrecycles.org/

[16] https://www.senat.fr/leg/exposes-des-motifs/ppr22-526-expose.html#:~:text=%2D%20la%20directive%2094%2F62%2F,libre%20circulation%20et%20de%20concurrence.

[17] https://www.lemonde.fr/archives/article/1992/08/22/point-l-elimination-des-dechets-la-polemique-relancee-en-allemagne_3900473_1819218.html

[18] https://reseauactionclimat.org/subventions-energies-fossiles-ou-sont-passes-11-milliards-euros/

[19] https://obsolescence-programmee.fr/concepts/

Business models in the linear economy

In classical industrial thinking, company performance is viewed as a sequence encompassing quality, productivity, and profitability. Quality is perceived as a stable, measurable dimension applicable to both goods production and service delivery. This approach emphasizes quantifiable elements, such as time spent or the number of contacts or operations performed, viewing production in terms of a correspondence between human labor and machine operation. Such a standardized view of quality makes it easier to identify tasks that can be automated and clearly assess the efficiency of the value creation process. The division of labor by task becomes possible because of this assumed stability of quality, and productivity can be improved through three principal means: economies of scale, work intensification, and technical innovation. A manager's ability to optimize productivity through these means is crucial to developing the production unit's profitability.

The geopolitical problem of the linear economy

The current linear economic model makes industry vulnerable to volatile raw material prices and uncertainty about availability, exacerbated by the risk of resource depletion. This problem is particularly pronounced in regions that lack these raw materials and therefore depend on imports (Collard, 2020). This situation exposes industrial countries such as France to geopolitical dependence on resource-rich countries, increasing their vulnerability.

3. Current developments

3.1. Current developments

The emergence of a functional economy

Faced with the challenges of natural resource depletion and growing environmental pressure, the circular economy offers both a viable solution and an opportunity to renew existing business models.

The circular economy thus drives changes in business models by encouraging a shift toward the functional economy, an approach to the servitization of both industry and the service sector (Demissy & Le Dilosquer, n.d.). Servitization concerns specific changes in the value creation process brought about by the development of relational aspects—co-activity—and intangible dimensions of activities (Demissy & Le Dilosquer, n.d.). By replacing the sale of goods with the sale of their use or function, the functional economy therefore seeks to maximize the use of goods and services while minimizing material and energy consumption, in line with circular economy principles. The aim is to create the greatest possible use value over the longest possible period.

There are several types of functional economy models: collective consumption, sales of use functions, and outcome-based contracting (Niel, 2014).

Collective consumption: This includes models such as short-term rental and car sharing. These models intensify product use, reducing the total number of products needed and helping lower environmental impacts. Examples include companies such as Lynk and co and ELIS, a specialist in professional textile services that retains ownership of textiles while providing laundry and maintenance services.[20]

Sales of use functions: These typically involve leasing or long-term rental, with the supplier retaining ownership and control of the product, maximizing its life cycle and minimizing environmental impacts through better maintenance and recycling. Companies such as Michelin, Interface, and Philipps exemplify this model.

[20] https://www.circul-r.com/ressources/economie-de-la-fonctionnalite

Interface Inc. offers carpet leasing, illustrating the sale-of-use-functions model by maintaining product ownership and focusing on reuse and recycling.

Michelin sells the use of tires through a service model in which customers pay according to distance traveled rather than purchasing tires outright. This model encourages Michelin to design tires that last longer and improve fuel efficiency.

Xerox has adopted a service model in which it charges customers according to the number of copies made instead of selling photocopiers. This model encourages Xerox to create durable machines and provide maintenance services to ensure long-term functionality.

Outcome-based contracting: This model guarantees that customer needs will be met, regardless of the combination of products and services used. It involves a performance guarantee, often used in energy or maintenance services. Energy efficiency service companies (SSEE) contract to improve the energy efficiency of their customers' facilities, committing to measurable results.[21]

The experimental AFNOR XP X30-901 standard

Companies have a wide range of options for changing their business models, including through the experimental AFNOR XP X30-901 standard, an innovative French circular economy initiative. First published in October 2018, this standard responds to current environmental challenges such as climate disruption, biodiversity loss, waste accumulation, and the degradation of natural environments. It aims to promote an economic model that reduces natural resource use by replacing linear logic with a circular and sustainable approach.[22]

AFNOR XP X30-901 is an experimental, voluntary standard. Rather than imposing binding obligations, it provides guidelines for managing circular economy projects across seven main areas of action: sustainable sourcing, ecodesign, industrial symbiosis, the functional economy, responsible consumption, extending useful life, and effective management of end-of-life materials and products.[23] It encourages organizations to adopt a variety of initiatives to optimize natural resource use and limit waste generation while incorporating the three dimensions of sustainable development: environmental, economic, and societal.

Nevertheless, applying this standard can be difficult for some companies because it requires major changes in production and management, demanding substantial investments of time, money, and expertise. Successful implementation also requires specialized skills that are not always available within every company.[24] In addition, the standard's effectiveness depends on the commitment of all relevant actors, which can be difficult in large organizations. Finally, because the standard is based on guidelines rather than strict rules and requires specific monitoring systems, its effectiveness is difficult to assess.

Recycling challenges

In the twenty-first century, recycling has become more complex as the diversity of recyclable materials has increased, particularly plastics and electronic devices. Technical and economic challenges have emerged, especially in the efficient collection, sorting, and reprocessing of recyclable materials.[25,26]

[21] https://www.johnsoncontrols.com/

[22] Economie circulaire : la France innove avec la norme XP X30-901 (afnor.org)

[23] L'AFNOR publie une norme sur l'économie circulaire (XP X30-901) (economiecirculaire.org)

[24] https://circulareconomy.europa.eu/platform/en/knowledge/circular-economy-and-voluntary-standard-6-companies-share-their-experience

[25] https://www.ellenmacarthurfoundation.org/articles/recycling-and-the-circular-economy-whats-the-difference

[26] https://greenly.earth/en-us/blog/company-guide/what-is-upcycling

Recycling is not always efficient in terms of the energy resources consumed relative to the energy and resources saved. Recycling certain materials, such as plastic, can be complex and costly and may not always yield high-quality products.

Contamination of recyclable materials by other waste can render some batches unrecyclable, reducing the overall effectiveness of the recycling process.

Recycling depends heavily on markets for recycled raw materials. Price fluctuations can make recycling less economically viable, reducing the incentive to recycle, particularly without subsidies or government support.

Although recycling is a key component of the circular economy, it is not always circular. For example, many recycled products are downcycled, meaning that they are transformed into lower-quality products that often cannot subsequently be recycled. This can increase waste rather than reduce it.

The repairability index: A link to ecodesign

In France, the major repairability initiative is the repairability index, introduced by the Anti-Waste Law for a Circular Economy (AGEC). Since 2021, this index has been mandatory for certain categories of electronic products and household appliances, such as smartphones, laptops, televisions, washing machines, and lawn mowers. The list has expanded since November 2022.[27] The index rates products on a scale of zero to ten based on criteria such as spare parts availability and cost, ease of disassembly, the availability of technical repair documentation, and a freely defined criterion specific to each product type. The repairability index is intended to become a durability index, providing information about both repairability and robustness.[28]

Although France is a European pioneer with this repairability index, other countries are considering similar measures. Belgium, for example, is preparing legislation based on the French model, scheduled for implementation by the end of 2024.[29]

As concrete examples of products meeting these criteria, companies such as Samsung and Apple have been cited for their efforts to make their products easier to repair. Samsung has made numerous disassembly manuals available, and Apple has improved repair procedures to increase its repairability scores, notably by changing the procedure for replacing the iPhone 13's front camera.[30]

Upcycling (upgrading) and remanufacturing

Upcycling (upgrading) involves transforming end-of-life materials or products into new objects of greater value. This practice is a pillar of the circular economy, which seeks both to recycle waste and to recover value from it.[31] Examples include turning used tires into belts or wine bottles into lamps, illustrating creativity and innovation in recycling. Upgrading refers to improving and updating products to increase their functionality beyond the original specifications, often through modular design. Remanufacturing, meanwhile, involves disassembling and restoring used products for reuse, offering a sustainable alternative to consuming new products and reducing waste.[32]

Repairability and remanufacturing

Alongside repairability, which aims to facilitate product maintenance and repair to extend product life, there is also remanufacturing. Remanufacturing involves restoring used products for a new period of use, an advanced form of recycling. It goes beyond processing materials by rebuilding the product using existing

[27] https://www.economie.gouv.fr/dgccrf/de-nouveaux-produits-concernes-par-lindice-de-reparabilite

[28] Why France's new 'repairability index' is a big deal | Grist

[29] Why the repairability index needs to be European in scope - APPLIA (applia-europe.eu)

[30] Indice de réparabilité, un an après | Actualités iFixit

[31] https://greenly.earth/en-us/blog/company-guide/what-is-upcycling

[32] https://remancouncil.org/what-is-remanufacturing/

parts wherever possible. Both contribute to the circular economy by keeping products in use longer, thereby reducing waste and the consumption of new resources.

The social and solidarity economy (SSE)

The social and solidarity economy (SSE) is a sector composed of organizations that seek to reconcile economic activity with social equity. These organizations include cooperatives, associations, foundations, and social enterprises operating with goals of solidarity and social benefit. The SSE emphasizes values such as the primacy of people and social purpose over capital, democratic governance, and the reinvestment of profits to serve social objectives. The circular economy, which aims to maximize resource reuse and minimize waste, is naturally aligned with the SSE in promoting sustainable and responsible practices. SSE enterprises often adopt practices that support the circular economy, such as recycling, repair, reuse, and the use of renewable resources.

Some examples of French enterprises at the intersection of CE and the SSE include:

Envie—This French work-integration network specializes in collecting, sorting, repairing, and selling refurbished household appliances. Envie combines the circular economy with the SSE by creating jobs for people facing barriers to employment while promoting appliance reuse to reduce waste.

Emmaüs—Known primarily for its solidarity initiatives, Emmaüs also operates on a circular economy model by collecting, refurbishing, and reselling secondhand goods. This finances social initiatives while reducing the environmental impact of waste.

Le Relais—Another French organization that collects used clothing for resale or recycling, creating work-integration jobs for disadvantaged people while reducing textile waste.

The sharing economy

The sharing economy involves business models in which platforms facilitate temporary access to goods and services, often through private providers and intermediaries that simplify transactions. It encourages optimal resource use, promoting sharing and reuse to reduce waste and environmental impacts. This approach shifts the focus from ownership to use—for example, through Lynk and co vehicle sharing—increasing efficiency and reducing the material footprint.

4. Foresight exploration

4.1. Structural trends

Following our analysis of a report on structural trends, we present those that seem likely to have the greatest influence on the evolution of industry and its business model (Megatrends Hub Competence Centre on Foresight Joint Research Centre, n.d.):

1. **Worsening resource scarcity**—This trend highlights the growing pressure on natural resources caused by unsustainable consumption and production. In an industrial context, it underscores the urgency of adopting circular economy models to minimize waste and optimize resource use.

2. **Climate change and environmental degradation**—The effects of climate change and biodiversity loss require a transformation toward more sustainable practices. For industry, this means investing in clean technologies, improving energy efficiency, and reducing greenhouse gas emissions.

3. **Accelerating technological change and hyperconnectivity**—Technological innovation offers new opportunities for the circular economy, particularly through the development of sustainable materials, advanced recycling, and online platforms that facilitate the sharing and reuse of goods.

ADEME's foresight report (ADEME, 2017) also shows that the functional economy is emerging as a structural trend because of its ability to meet sustainable development imperatives by prioritizing use and

service quality over ownership and the quantity of goods. This model stands out particularly in saturated markets, offering renewal for declining traditional business models. Supported by public policies such as France's Grenelle de l'environnement initiative and Energy Transition for Green Growth Law, the functional economy is gaining popularity and business adoption. It promotes more efficient resource management and strengthens the local social and economic fabric through a more collaborative, community-based approach suited to contemporary sustainability and efficiency challenges.

4.2. Uncertainties

The challenges of implementing EPR

France's adoption of the principle of extended producer responsibility (EPR) marks an important step in waste management, seeking to transfer responsibility from local authorities to producers. This change encourages producers to design more sustainable products and assume responsibility for waste collection and recycling, particularly for waste electrical and electronic equipment (WEEE), which contains both hazardous and valuable materials (Micheaux, 2020).

Implementing EPR requires collective action and collaboration among producers, distributors, recyclers, and local authorities. Producer responsibility organizations, private nonprofit entities approved by the state, play a crucial role in this process. They collect producers' environmental fees, which finance waste collection and recycling.

However, the EPR system faces significant challenges. Despite its successes, the need for greater transparency, better traceability of waste flows, and stronger governance of producer responsibility organizations has become apparent. The 2020 Anti-Waste Law for a Circular Economy seeks to address these challenges by strengthening EPR, extending its principles to new sectors, and increasing ecodesign and recyclability requirements.

In practice, collaboration between producers and other stakeholders under EPR does not always run smoothly. Tensions exist, particularly over the distribution of waste management costs and producers' level of commitment to waste reduction and the circular economy. By tightening requirements and introducing new sectors, the 2020 law seeks to address these difficulties by encouraging closer collaboration and making the actors involved more accountable.

Reluctance to use nanomaterials

Reluctance to use nanomaterials stems from their dual character: on the one hand, their revolutionary potential for the circular economy through innovative materials such as eutectogels, mycelium-based materials, and advances in nanoagriculture and plasma agriculture; on the other, the risks they pose to human health and the environment. These materials offer substantial sustainable development opportunities, ranging from improving the durability of electronic devices and health monitoring to reducing the environmental impact of food production (Eulaerts et al., n.d.). However, increased production and use of nanomaterials raise health and safety concerns, including the risk of lung inflammation similar to that caused by asbestos and increased worker exposure.[33]

The transition to circular economy practices therefore requires balancing the benefits of nanomaterials with the management of their risks. This involves developing regulatory frameworks and policies that encourage responsible innovation, the adoption of safer technologies, and a better understanding of nanomaterials' potential impacts. It also requires industrial business models that incorporate sustainability, safety, and environmental responsibility while drawing on circular economy principles to minimize ecological impacts. Thus, although nanomaterials offer significant opportunities for innovation and sustainable development,

[33] https://www.niehs.nih.gov/health/topics/agents/sya-nano

their use underscores the need for a cautious, regulated approach to protect human health and the environment.

4.3. Weak signals/seeds of change

Urban mining and material passports take shape

This key factor, at the intersection of a weak signal and a trend, highlights an innovative shift toward sustainability in construction and real estate. The approach treats buildings at the end of their life cycles as "material banks": Instead of demolition generating waste, materials are viewed as valuable resources to recover and reuse.[34]

A key element of this strategy is the development of "material passports" documenting the types, values, and ease of disassembly of materials in a building. The Dutch company Madaster, for example, pioneered the creation of a digital library that catalogs buildings by their constituent materials. This helps plan future reuse and recycling of building components.

Various practical applications of these concepts are evident worldwide. In Amsterdam, projects such as Beach Island require buildings to have a material passport so that materials can be recovered efficiently after demolition. Similarly, the conversion of a 1930s building into the modern Blique by Nobis hotel in Stockholm reused materials to reduce carbon emissions substantially.

Other innovative uses of recycled materials include the Epic office building in Malmö, which used PET bottles for soundproofing and reused concrete for flooring. The Stationsplein project in Leiden and the Dala recycling depot in Borlänge, Sweden, demonstrate community and municipal cooperation in applying circular economy principles to construction and demolition processes.

These initiatives reduce waste and carbon emissions while also creating new business and design models. Such models focus on sustainability by promoting material reuse throughout buildings' life cycles, from construction to demolition. Embodied in urban mining and material passports, this approach represents a significant trend toward more sustainable urban development and construction practices.

Atomic-scale manufacturing

Atomic-scale manufacturing, a breakthrough in nanotechnology and materials science, enables materials and devices to be built with unprecedented precision. The technique manipulates atoms and molecules to produce highly precise, virtually defect-free structures, significantly improving product performance and efficiency. It has immense potential to transform industries by optimizing material properties, enabling the miniaturization of electronic components for more powerful devices, and improving energy efficiency, thereby contributing to sustainability and climate change mitigation efforts.

Atomic-scale manufacturing has considerable potential to support circularity and address raw material shortages by optimizing material use and supporting sustainable manufacturing processes essential to circular economy principles. Research at Oak Ridge National Laboratory (ORNL) demonstrates its key role in developing innovative materials such as graphene with remarkable properties, including self-healing.[35] This precision enables the creation of more durable and efficient materials, reducing frequent replacements and minimizing waste. Sustainable manufacturing practices also support supply chain management and the reduction of environmental impacts, advancing circular economy objectives for a more sustainable and efficient industry.

[34] https://www.swecogroup.com/urban-insight/circularity/circular-construction-an-opportunity-we-cant-waste/

[35] https://www.ornl.gov/news/new-insights-advance-atomic-scale-manufacturing

Graphene applications may be important for industry in France and could contribute significantly to ecodesign and the protection of natural resources.[36,37] Research on graphene indicates a potential inflammatory risk without direct toxicity at moderate doses. Environmental concerns also exist, particularly regarding its effects in water. Further studies are needed for a comprehensive assessment of its effects.[38]

The household as a circular economy hub

Current household use of natural resources and energy, as well as household emissions, are unsustainable, particularly in wealthy countries. This has prompted the imagining of alternative forms of economies and households that use renewable energy and recycle materials in closed loops, following circular economy principles. Although these principles primarily apply to entire economic systems, households could adopt them more widely in the future, potentially turning household waste into sources of income and helping conserve the planet's natural resources (Dufva & Rowley, 2022).

Viewing the household as a circular economy hub could fundamentally transform traditional industrial and manufacturing models by integrating waste reduction, recycling, and reuse directly into economic systems. This perspective suggests a future in which households would operate in closed loops, managing resources and waste sustainably. For industry, it could open innovative business models centered on recycling household by-products and decentralizing waste treatment while fostering closer cooperation between industries and households, with one party's waste becoming the other's resource. This model could significantly reduce environmental impacts, promote energy conservation, and offer households new sources of income or savings while providing industries with cheaper, locally sourced materials.

A local example suggesting that this weak signal could develop into a trend is ABCDE groupe in the Vosges,[39] which collects cow manure from farmers for biomethanation.

What if consuming means (re)producing?

Imagine a world in which repairing and modifying what we already own becomes the norm, using local materials and waste as raw materials and opening the way to craft- and repair-based initiatives. This weak signal suggests a profound transformation in consumption and production toward a circular economy and sustainability. For industry, it could mean adopting business models centered on repair, recycling, and customization instead of mass-producing new goods. Industries could collaborate with consumers by offering repair services or using recycled and locally sourced materials in production. Such cooperation could reduce waste while strengthening ties between producers and consumers, fostering a shared commitment to sustainability.

Charging for goods and services—but in a currency other than money

In a future in which consumption culture is challenged by repair cafés and circular economy business models, the idea of paying with visibility, as Toronto's Pick Me Up café does through social media, raises the possibility of a new form of commerce.[40] Although this approach to consumption and charging for goods and services is still at a very early stage, it could provide food for thought. For example, in connection with the preceding weak signals, one could imagine giving products in exchange for recyclable waste brought in by

[36] https://www.lesechos.fr/partenaires/bpifrance/des-francais-bientot-champions-deurope-de-production-de-graphene-1975143

[37] https://fr.fashionnetwork.com/news/Candiani-cree-un-jean-a-base-de-graphene-un-denim-high-tech-aux-proprietes-thermoregulatrices,1525626.html

[38] Le graphène est-il toxique? | CNRS Le journal

[39] https://organique.abcde-groupe.com/

[40] https://thevarsity.ca/2021/09/26/pick-me-ups-toronto-pop-up/

customers or offering discounts or free services in exchange for volunteering or community contributions. Asking users to pay with their skills or other nonmonetary resources remains another avenue to explore.

Cooperation across sectors and industries

This weak signal illustrates how seemingly separate industries can collaborate to address shared challenges, particularly environmental ones. Consider Stora Enso, a company specializing in wood and cellulose production, which partnered with the clothing brand Filippa K to create a limited edition of garments made from cellulose fibers. This collaboration directly addresses environmental problems facing the textile industry, particularly excessive resource consumption and waste generation. By using cellulose derived from wood, a renewable resource, Filippa K can reduce its carbon footprint and offer customers more sustainable alternatives.[41]

This approach is also evident in Toast Ale's initiative to use unsold bread to replace some of the malt in beer production. By incorporating bread, one of the most heavily wasted foods, into the brewing process, Toast Ale recovers value from waste and offers an environmentally responsible solution by reducing demand for malt, another agricultural resource. This shows that traditional practices, such as the use of bread in beer documented by the ancient Mesopotamians, can be adapted and modernized to address today's challenges.[42]

New knowledge in established industries

Integrating new scientific and technological knowledge into traditional sectors can radically transform long-established industries. This is particularly evident in the bioeconomy, where advances in biotechnology and green chemistry are reinventing the building materials industry, notably concrete.

1. The bioeconomy and the concrete industry

Traditionally, concrete production is energy-intensive and generates high CO2 emissions, mainly because of limestone calcination in cement production. Applying bioeconomy knowledge, however, opens the way to significant innovations. For example, using biological binders or composite materials incorporating natural fibers can both reduce the sector's carbon footprint and improve the recyclability of finished products.

Companies such as Solution Biosys offer sustainable alternatives by developing biobased building materials that are less dependent on nonrenewable resources. These innovations can include using agricultural or forestry by-products in concrete, helping create a greener life cycle for building materials.[43]

2. Lignin: A key to the energy transition?

The battery industry, traditionally dependent on materials such as lithium and cobalt, is exploring new possibilities with lignin, a wood component, to reduce dependence on imports and minimize environmental impacts. The Finnish company Stora Enso has developed battery anodes called Lignode using lignin, offering a greener, less energy-intensive solution.

Lignin anodes not only reduce the carbon footprint but also improve battery performance, with substantially shorter charging times. However, scaling up this technology poses technical challenges and requires sustainable forest resource management to avoid depleting ecosystems.[44]

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[41] https://www.thelocal.se/20180418/this-nordic-company-wants-you-to-wear-trousers-made-from-trees-stora-enso-tlccu

[42] https://www.ellenmacarthurfoundation.org/circular-examples/brewing-beer-from-surplus-bread?sortBy=rel

[43] https://www.solution-biosys.fr/

[44] https://www.renouvelle.be/fr/batterie-electrique-le-bois-de-nos-forets-comme-ressource-locale/

4.4. Controversies

Continued extraction of natural resources

Product life cycle assessment, particularly for electronic equipment, highlights a crucial and often overlooked issue: natural resource extraction. Despite advances in ecodesign and the recycling of waste electrical and electronic equipment (WEEE), these initiatives struggle to meet growing demand for electronic equipment. This increase in demand is attributable to several factors, including lower costs through industrialization and offshoring, technological advances, shorter product life spans for marketing and cost reasons, and rising demand in countries aspiring to Western living standards. The situation is compounded by the approaching depletion of certain natural resources essential to producing this equipment.

Like fossil fuels, natural resources are not inexhaustible. The electronics industry consumes vast quantities of diverse raw materials, and we are approaching their depletion faster than expected. Extraction of these materials, often in developing countries, poses serious environmental and social problems. For example, coltan mining in the Democratic Republic of the Congo fuels an armed conflict over control of this strategic resource.

Data from PCMAG.com indicate depletion dates for several key resources, such as terbium in 2012, hafnium in 2018, and other materials—silver, antimony, palladium, gold, zinc, indium, lead, tantalum, copper, uranium, nickel, oil, and platinum—between 2021 and 2064. This situation raises concerns about the sustainability of our resource consumption and the need to increase recycling. Currently, materials such as lead (72%), aluminum (49%), and gold (43%) have substantial recycling rates, while others, such as gallium, indium, phosphorus, platinum, and uranium, are not recycled.[45]

4.5. Disruptions

A new energy era

The onset of a new energy era, marked by technological breakthroughs in nuclear research, has significant implications for industry in France and Europe. These advances, particularly the development of new materials such as nonbrittle carbon composites and superconductors, promise to make nuclear energy extremely inexpensive. Using these materials could revolutionize energy production by enabling safer, more efficient nuclear reactors (Miles et al., n.d.).

This disruptive development could have positive impacts. For example, significant improvements in energy efficiency and lower nuclear energy production costs could stimulate the economy by reducing costs for industries and households. They could also strengthen European industries' competitiveness in the global market.

Furthermore, the ability to produce nuclear energy more locally and economically could allow France and other European countries to reduce their dependence on fossil fuel imports, strengthening their energy security.

Finally, implementing these new technologies and materials in nuclear energy production would also align the industry with circular economy objectives by minimizing nuclear waste and optimizing resource use.

Nevertheless, this disruptive development is not without negative impacts. Despite safety improvements, expanding nuclear energy production raises concerns about nuclear waste management and accident risks. Maintaining high safety standards could entail additional costs and require substantial research and development investment.

[45] https://www.techniques-ingenieur.fr/actualite/articles/informatique-et-epuisement-des-ressources-naturelles-6484/

Public opposition to nuclear energy in Europe, driven by environmental and safety concerns, could slow the adoption of these new technologies. Public awareness and acceptance remain major challenges for the nuclear industry.

Unequal access to advanced nuclear technologies could widen the gap among European regions in energy capacity and innovation, exacerbating regional inequalities.

Developing nuclear reactors based on new materials could also contribute to global polarization, with countries able to invest in these technologies enjoying greater energy independence while others remain dependent on fossil fuels or imported energy.

Converting waste into energy

The emergence of a revolutionary energy system capable of converting various types of waste into energy, primarily through gasification, is a disruptive development that could radically transform industry and society in France and Europe. This technological development promises clean, safe, free energy produced locally, reducing dependence on external power plants. Arising from innovation policies focused on new technologies and research into waste as a "new raw material," this advance suggests that traditional energy infrastructure could become obsolete (Miles et al., n.d.)(Miles et al., n.d.)(Miles et al., n.d.).

The impacts are positive for society and the environment. Producing free energy from waste would have a profoundly positive impact on people's lives by providing clean energy and reducing waste. It would also support circular economy objectives by recovering value from waste as a resource and reducing the environmental impact of energy production.

This technology would also enable energy independence. For French and European industry, it offers the possibility of substantially reducing dependence on imported fossil fuels by promoting energy autonomy based on local renewable resources.

Finally, developing and commercializing these new technologies could stimulate innovation, create new businesses and jobs in renewable energy, and thereby strengthen the economy.

Nevertheless, this wild card represents a significant risk for traditional energy industry players. Falling demand for conventional energy could cause substantial economic losses in the oil, gas, and coal sectors.

The transition to decentralized energy production would require substantial infrastructure and research investment to ensure the safety and efficiency of new energy facilities.

Adapting regulatory frameworks and ensuring that the benefits of this free energy are distributed fairly would pose significant challenges. Policies to support the retraining of workers and the restructuring of affected industries would be urgently needed.

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