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# Potentials and Prerequisites on the Way to a Circular Economy: A Value Chain Perspective on Batteries and Buildings

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**Abstract:** It is becoming increasingly clear that linear modes of production and consumption are unsustainable. A circular economy would help to minimize both environmental and social problems. As a result, the concept is gaining momentum in the political discourse. However, current policies do not seem sufficient to transform linear value chains to circular ones. This paper compares the potentials of and prerequisites for a circular economy along two important value chains. As a best practice example, the legal framework along the battery value chain is analyzed. This analysis is used to derive recommendations for how to improve the legal framework along the building value chain. We find that the battery value chain is already addressed by targeted instruments and the instruments addressing the building value chain have to be aligned and their credibility improved through mandatory requirements. A value chain-specific approach to develop the legal framework is promising for key sectors, while both general frameworks and value chain-specific instruments are required to fully exploit the CE for every product.

**Keywords:** circular economy; buildings; batteries; value chain; legal framework

**Citation:** Lotz, M.T.; Barkhausen, R.; Herbst, A.; Pfaff, M.; Durand, A.; Rehfeldt, M. Potentials and Prerequisites on the Way to a Circular Economy: A Value Chain Perspective on Batteries and Buildings. *Sustainability* **2022**, *14*, 956. https://doi.org/10.3390/su14020956

Academic Editors: Henning Friege, Antonio Boggia, Knut Blind, Simone Wurster, Rainer Walz and Katrin Ostertag,

Received: 30 September 2021
Accepted: 12 January 2022
Published: 14 January 2022



## 1. Introduction

It is becoming increasingly clear that linear modes of production and consumption are unsustainable. As a result, there are calls for a move towards a circular economy (CE) in the European Union (EU). In December 2019, the European Commission published its communication on the European Green Deal highlighting the aim of mobilizing industry for a clean and circular economy, in which growth is decoupled from resource use [1]. Such a move could help to minimize both environmental and social problems. It is acknowledged that the CE can reduce import dependencies and supply chain risks. At the same time, the CE is an important pillar in reducing the demand for (energy-intensive) raw materials and the related carbon emissions in the context of the climate goals set out by the 2015 Paris Agreement [2].

The European Commission published a new Circular Economy Action Plan (CEAP) in March 2020 to exploit these potentials. This plan focuses on consumer empowerment, waste reduction and sustainable product policy. The latter aims to make products last longer through repair and re-use as well as by increasing the proportion of secondary materials in these products [3]. In the CEAP, the European Commission prioritizes sectors and products with high resource demand, associated environmental impacts and high CE potentials, such as electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, as well as food.

Successfully implementing CE actions requires an appropriate Quality Infrastructure (QI), which not only ensures quality but also acts as an enabler through regulation, common standards and certification. The International Network on Quality Infrastructure

(INetQI) defines QI as "The system comprising the organizations (public and private) together with the policies, relevant legal and regulatory framework, and practices needed to support and enhance the quality, safety and environmental soundness of goods, services and processes." INetQI further emphasizes QI's reliance on metrology, standardization, accreditation, conformity assessment and market surveillance [4]. Despite the importance of a well-developed QI to advance the CE, only limited efforts have been made so far to establish one. At the global level, the United Nations Industrial Development Organization (UNIDO) recently published a call for the establishment of a QI for a sustainable future [5], while some national metrology and accreditation institutions have joined forces to investigate how to establish a QI in the context of circular and green economy goals [6]. Other efforts focus on individual elements of QI, such as norms and certification schemes. For instance, the International Organization for Standardization (ISO) formed a new technical committee (ISO/TC 323) in 2019, which is developing a number of standards in the field of the CE [7].

The situation is similar at the European level. While a concerted overall effort to establish a QI for the CE still needs to be fostered, there are individual initiatives focusing on elements of the QI system. The CEN-CENELEC Joint Technical Committee 10 of the European Committee for Standardization has published a series of standards on material efficiency in energy-related products [8]. At the national level, the German Institute for Standardization, for example, recently initiated the development of a standardization roadmap for the CE in response to the EU's policy initiatives cited above [9]. In contrast to these scattered efforts, the regulatory framework of the European Commission addressing relevant aspects of the CE is theoretically already quite broad in its scope. Unlike the political awareness of CE potentials, however, actual implementation is not progressing at the desired speed [10]. One main reason for this is a discrepancy between the political discourse and the systematic implementation of framework conditions [11]. The current legal framework appears inadequate to provide efficient prerequisites for a CE, as it is too fragmented and lacks a systematic perspective of the products and sectors mentioned [12]. This problem is further compounded by the heterogeneity of the EU legal framework addressing the CE [11,12]. Since the legal framework is relatively mature, but ineffective in some respects, our analysis focuses on this aspect of QI for the CE.

In order to tackle this discrepancy, this paper compares two of the priority sectors of the CEAP—batteries and buildings. The battery sector was selected because it has been the subject of intense political discussion for some time, and a regulation comprehensively addressing the CE was already proposed at the end of 2019. This proposal is very ambitious and understood as a guiding benchmark for CE policies, as it holistically addresses aspects of the entire product's value chain. In contrast, the building sector is covered by diverse policies with varying focal points, which pose challenges with respect to implementation and enforcement. The current set of policies is therefore characterized by a high potential for improvement.

These two sectors have different characteristics and thus different requirements for a CE. The demand for batteries is growing rapidly and this trend is expected to continue especially due to the increase in sales of electric vehicles (EVs). The CE is of particular importance here to reduce the demand for raw materials in view of the high level of global trade and supply chain risks. The buildings sector is characterized by a well-established value chain and little cross-border trading activity. CE can contribute to decarbonizing the related basic material industries (e.g., steel and cement) by reducing the demand for new buildings, e.g., by extending the lifetime of existing buildings. CE is also becoming more important, given the increasing demand for insulation materials needed in the energy transition.

To analyze and improve the existing legal framework, we provide a systematic overview of this framework for both sectors and then suggest how to improve the legal framework for the building sector's value chain based on our analysis of the battery value chain.

We answer the following research questions with the aim of suggesting how to improve the prerequisites for the transition of the building sector to a circular model:

1. How does the current legal framework cover the exploitation of CE potentials?
2. Which gaps can be identified along the value chains and what are the differences between them?
3. What recommendations can be made to improve the legal framework?

## 2. Materials and Methods

Important definitions and concepts as well as the sector characteristics necessary for this analysis are described below. The CE concept is used as an umbrella for diverse material-related strategies [13]. The initial idea was based on the transformation from a linear to a circular economy and hence on the cycling of materials. More recent principles also include material efficiency and material substitution [14,15]. These CE strategies are implemented through so-called CE actions, and the preferable impact of these actions are described as CE potentials.

Several analyses attempted to define and delimit the underlying concept of the CE [2,13,16–18]. Two of these definitions are relevant for our paper, as they share the product focus of the CEAP. Alhawari et al. describe the CE as "the set of organizational planning processes for creating, delivering products, components, and materials at their highest utility for customers and society through effective and efficient utilization of ecosystem, economic, and product cycles by closing loops for all the related resource flows" [16]. In contrast, Kirchherr et al. define the CE "as an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes" [17].

The definition of Alhawari et al. highlights the value chains for analyzing the CE. The value chain stages for our analysis are defined in Table 1. The significance and characteristics of the stages can vary depending on the value chain considered. Overlaps between the stages are commented on if necessary, as the distinction is not always clear-cut. Allocating CE potentials and prerequisites to the stages is based on the impact of the identified actions and not the stage of their implementation.

**Table 1.** Definition of the value chain stages considered in this contribution, adapted from [19,20].

| Value Chain Stage | Description |
|---|---|
| Raw material | Sourced raw materials used in the value chain, secondary materials and material substitutes |
| Processing/ manufacturing | Manufacturing and processing of materials from the raw material stage and intermediates |
| Use | Use of the manufactured/produced goods from the processing/manufacturing stage and activities prolonging the use phase (e.g., repair) |
| Recycling | Recycling, downcycling and upcycling of the goods from the use stage |
| Recovery/disposal | Recovery and disposal of the goods from the use stage |

The definition of Kirchherr et al. introduces another important concept: the 3Rs (reduce, reuse and recycle). It is commonly used for prioritizing CE actions [17,21]. Within the 3R framework, material efficiency has the highest priority, while lower priority is assigned to recycling [17,21]. Material substitution is not covered and is thus assigned the lowest priority. The 3R framework can be expanded to 9R (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover) [17,18]. Table 2 shows examples of CE actions and their allocation to the 9Rs, the CE strategy and the value chain stage.

**Table 2.** Exemplary CE actions and allocation to the 9Rs, the CE strategy and the affected value chain stage, adapted from [14,15,18,22].

| Value Chain Stage | Material Efficiency | Recycling | Material Substitution |
|---|---|---|---|
| Raw material | *Reduce* Minimize the use of raw materials | *Recycle* Use of secondary instead of primary materials | *n/a* Use of low impact instead of high impact materials |
| Processing/manufacturing | *Reduce* Minimize losses and reduce material use | n/a | n/a |
| Use | *Rethink, Reuse, Repair, Refurbish, Remanufacture and Repurpose* Increase use intensity | n/a | n/a |
| Recycling | *Reduce* Minimize losses | *Recycle* Material upcycling, recycling or downcycling | n/a |
| Recovery/disposal | n/a | n/a | n/a |

The characteristics and CE potentials of the battery and building value chains are described in the following sections. The CE actions are matched with the value chain stages to provide a common structure throughout this article. Additionally, the 9Rs are allocated to the CE actions.

### *2.1. Potentials along the Battery Value Chain*

The battery market has grown steadily in recent years, especially due to the sharp increase in the demand for batteries needed for electric mobility applications [23]. In the German battery market, for example, rechargeable batteries surpassed non-rechargeable batteries (sales, on a weight basis) in 2019, and lithium-ion batteries (LIBs) accounted for more than 80% of these rechargeable batteries [24].

LIBs have become the dominant battery technology in the mobility sector due to their higher energy density compared to other battery types, such as nickel-cadmium or nickel-metal hydride [25]. In 2019, mobility applications (for instance, passenger cars, trucks, buses and e-bikes) accounted for around 70% of global LIB demand (measured by energy), and almost half for passenger car EVs alone. Consumer electronics and energy storage accounted for the remaining 30% [26].

Batteries are an essential component of EVs and have a major share in their power-train costs, which are 54% higher than those for internal combustion engines [27]. Batteries can thus be considered one of the critical components for the decarbonization of road transport, a sector that accounted for 29% of the final energy consumption in the EU in 2019 [28].

LIBs require critical raw materials, some of which have very limited worldwide reserves, and imply import dependencies for the EU, especially in the case of lithium and cobalt. While Australia is the country that supplies the most lithium to the market, resources are concentrated in the so-called lithium triangle in South America (a region straddling the borders of Argentina, Bolivia and Chile), where almost 60% of the world's lithium resources are located [29]. In 2020, the EU added lithium to its list of critical raw materials due to the high import dependency [30].

Additionally, on the list of critical raw materials is cobalt, the highest priced metal used in LIBs, for which the supply chain is even less diversified. A total of 70% of global production in 2019 was mined in the Democratic Republic of Congo (DRC), which also holds the largest cobalt reserves [29]. Cobalt mining raises ethical concerns about working conditions, as an estimated 15–20% of cobalt extraction in the DRC takes place in artisanal mines, which pose severe risks for to health and safety [31].

In addition to EU import dependencies and supply risks for key materials, material mining and battery production are very energy-intensive [32], and the current end-of-life (EOL) treatment of batteries does not recover some of the key materials.

Overall, the battery value chain is now of strategic importance to the EU, and CE actions can reduce the economic risks due to import dependency and material shortage, and the environmental and social impacts along the supply chain. The following sections briefly discuss the relevance of CE along the battery value chain based on literature research and the current analyses.

#### 2.1.1. Scoping

The analysis of the CE potentials of the battery sector will focus on LIBs. Within LIBs, the focus is on the batteries used in electric passenger cars according to the EU definition [33]. Passenger cars are by far the largest share of electric vehicles (EVs) on the EU market [34]. Materials of particular importance are cobalt and lithium, which are classified as critical by the EU due to supply risks and high import dependency [30]. The CE actions assessed in this study focus on recirculating materials or products, rather than reducing material consumption or substituting high impact materials. We do not address possible shifts to other novel battery types or to other technologies.

#### 2.1.2. Identification of CE Actions

There are a number of potential CE measures in the battery sector, many of which were already considered by policy-makers in the December 2020 proposal for a revised regulation for batteries and waste batteries [31]. This proposal is described in detail in Section 3.1, as it is considered as a benchmark for CE policies. The list of potential CE actions are classified according to the 9R framework and the main value chain stage they address. Again, the order of the actions for each value chain stage reflects the prioritization according to the 9R Framework. It should be noted that many actions affect different stages, but for the sake of simplicity, each is assigned to only one stage (Table 3).

**Table 3.** List of the identified CE actions along the battery value chain, adapted from [35].

| | |
|---|---|
| **Raw Material** | |
| *Recycle* | Minimum quotas for recycled content in new batteries |
| **Processing/manufacturing** | |
| n/a | |
| **Use** | |
| *Rethink* | Information requirements concerning performance and durability |
| *Reduce* | Minimum performance and durability requirements |
| *Reuse, Repair, Refurbish* | Requirements for removability and/or replaceability |
| *Remanufacture, Repurpose* | Support the second life of LIBs by providing a clear legal framework, e.g., consider repurposed batteries as new products and not waste |
| *Remanufacture, Repurpose* | Integrate second-life uses into the design process, e.g., mandatory second life readiness |
| **Recycling** | |
| *Recycle* | Minimum collection targets for automotive LIBs |
| *Recycle* | Minimum recycling efficiency of the entire battery, or individual material, e.g., cobalt |

| | |
|---|---|
| *Recycle* | Setting up an electronic information exchange system for batteries, e.g., battery passport |
| **Recovery/disposal** | |
| *Recycle, Recover* | Implement extended producer responsibility (EPR) to incorporate waste management cost into product price |

2.1.3. Potentials of CE Actions

In 2019, the Joint Research Centre (JRC) conducted an in-depth study of the EU automotive LIB market [36]. The results showed that the number of batteries potentially available for second-use applications would increase sharply in the coming years. It was also shown that the second use of batteries leads to a significant stock of materials in second-life applications and thus delays the materials available for recycling.

Researchers conducted a similar analysis for the EU market as part of the preparatory study Ecodesign study for rechargeable batteries [37] in 2019, in particular to estimate the impact of longer lifetimes on battery demand. The results are in line with those from the JRC report and show a significant reduction in material demand due to longer battery lifetimes.

In a market that is experiencing rapid growth, such as the battery sector, true circular material flow will only be achieved once product sales are saturated. However, CE actions can already have a significant impact today. The JRC [36] and the Ecodesign study [37] show that large amounts of material will become available for recycling in the coming years. A stable inflow of batteries to recycling facilities needs to be secured. This depends on the battery collection rate and the second-life battery rate, among other factors. Giving LIBs a second life can reduce the emissions associated with battery production, but delays the inflow of materials to recyclers at the same time (and also reduces the demand for new batteries).

To achieve high recovery rates, recycling efficiencies can be set on a material-by-material basis, taking technological progress into account. The current recycling processes are optimized for the recovery of nickel and cobalt [38]. Lithium recovery is technologically feasible, but not yet state-of-the-art due to the more complex process [39] and the lower commodity value. However, recycling efficiencies of well over 90% are achievable [39], and lithium's economic importance for recyclers will likely grow due to the reduced cobalt content in new batteries [40]. Providing recyclers with detailed information about the materials contained in the battery can help them to increase efficiency of recycling. Such information could be provided in the form of a digital battery passport.

In addition, a stable secondary materials market could be created using a binding recycled materials quota. Limits must be set in a careful and flexible way that considers market growth to ensure that the recycling industry can meet the demand for secondary materials.

### *2.2. Potentials along the Building Value Chain*

The building sector is a significant one in most economies and accounts for a sizeable share of both energy demand and greenhouse gas (GHG) emissions. In 2017, this sector was responsible for 35% of global final energy use and 38% of energy-related carbon emissions [41]. Material production for buildings contributes greatly to GHG emissions and the second largest source of emissions across a building's lifecycle. If low-carbon energy is used during the use phase, material production is responsible for the largest share of GHG emissions [42,43]. The sector is important as it includes the production of vast amounts of energy-intensive and carbon-intensive products (e.g., concrete and steel) [44].

The single most important building product is concrete (and its precursor products cement and clinker) [44]. The cement industry faces special challenges due to its high process-related emissions, which account for two-thirds of the emissions generated in the production process. Burning cement clinker in rotary kilns releases chemically bound carbon dioxide from the limestone used, which cannot be avoided through conventional actions, such as switching to carbon-neutral energy sources, but is closely linked to the raw material and process used. Cement is normally produced within the EU and traded locally [45].

Another important basic material used in the building sector is steel. The sector currently consumes around 38% of the steel in Europe [46]. Reducing the demand for steel products can significantly decrease the GHG emissions related to steel production. Additionally, there are high potentials for secondary material use. This is likely to become even more relevant because secondary energy carriers, such as electricity and hydrogen, are needed for carbon-neutral steel production. The steel industry competes with other sectors for the use of these secondary energy carriers. Therefore, an ambitious increase in circularity and material efficiency is considered necessary for an efficient transformation of the energy system that aims to reduce final energy demand, lower the costs for renewable energies and grid expansion and decrease the import of secondary energy sources [47,48]. Unlike to cement, steel is traded globally.

In the context of the energy transition, another important issue is the use of materials for building insulation, particularly when buildings are deconstructed, reconstructed or renewed [49]. At present, only small quantities and volumes of insulation materials are recovered from such activities. However, these are expected to increase in the medium to long term—also based on the EU Renovation Wave Strategy published in 2020 [49–51].

Consequently, recent studies show that CE actions in the building industry could make a significant contribution to reduce GHG emissions in the European and global basic materials industries [15,42]. Based on previous work from [44,52], the following section briefly discusses the relevance of CE along the building value chain.

#### 2.2.1. Scoping

The following only considers material-related actions, targeting embodied emissions in buildings. Materials of particular importance in this context include cement, lime and plaster, fabricated metal products and basic iron and steel, rubber and plastic, as well as wood [52]. The production of cement and steel, in particular, is very energy-intensive and faces substantial challenges in the context of decarbonization [44,53,54]. For this reason, special attention is paid to actions reducing the impact of these intermediates. The actions that deal with the energy consumption in and energy provision for buildings are outside the scope of this contribution.

#### 2.2.2. Identification of CE Actions

In [52], an extensive literature review was carried out to identify the most relevant and impactful CE actions. Table 4 shows a non-exhaustive, simplified list of these CE actions, classified according to the 9R framework and the main value chain stage addressed. The order of the actions for each value chain stage reflects the prioritization of the 9R framework. Most of the actions can be further differentiated. For example, increases in material efficiency can take place in various ways (for instance, the reduction of over-specification in buildings, use of thinner materials and light-weighting).

**Table 4.** List of the identified CE actions along the building value chain, adapted from [44,52].

| **Raw Material** | |
|---|---|
| *Recycle* | Use of recycled materials |
| *n/a* | Use of low-carbon materials |
| *n/a* | Use of different binding agents in cement production |
| *n/a* | Use of alternative structural materials, e.g., wood/timber |

| Processing/manufacturing | |
|---|---|
| *Reduce* | Increases in material efficiency, e.g., lightweighting, reduce overspecification |
| *Reduce* | Reduction of losses, e.g., near-net-shape casting, 3D printing |
| *Reduce* | Lower clinker share in cement production |
| **Use** | |
| *Rethink* | Optimize space use in buildings |
| *Repair, Refurbish* | Extension of useful life |
| *Remanufacture, Repurpose* | Reuse building materials/components |
| **Recycling** | |
| *Recycle* | Design for disassembly and standardized building elements |
| **Recovery/disposal** | |
| *Recovery* | Use of waste for other purposes |

2.2.3. Potentials of CE Actions

The discussed potentials of CE action along the building value chain are based on existing studies and literature.

In [44], Rehfeldt et al. showed that actions to support material efficiency, CE and sufficiency can contribute substantially to the decarbonization of the building sector, yielding GHG emission reductions of around 58% (focusing on the emissions related to cement production, including transport), not taking into account structural changes in the building stock. The authors show that the manufacturing stage in cement production accounts for the highest share in both absolute emissions and saving potentials. However, the actions affecting the use stage of the value chain indirectly affect the manufacturing stage as well by reducing material demand and show significant potentials [44,52].

In [55], Allwood identified three important actions that could lead to significant reduction in material use and consequently GHG emissions in the building sector. First, efficient design in line with the Eurocodes (without using excess materials) can achieve substantial material savings; this effect is even more pronounced when combined with pre-fabrication. Second, designing flexible buildings to adapt to future needs can substantially prolong building lifetimes and thus reduce material demand. Third, using alternative materials that include the use of both natural as well as recycled/reused materials. Overall, Allwood estimated that it should be possible to use half the material for twice as long in the building sector [55].

Similar to [55], Material Economics identified designs to increase the lifetime and adaptability of buildings together with design-for-disassembly and the reuse of components as key actions to reduce material demand. In addition, material efficiency, increased standardization, recycling and new business models (to reduce the overall floor area needed) are deemed relevant actions [42]. Overall, Material Economics assumes a reduction of around 80 megatons of European carbon dioxide emissions (~−50%) from building materials by 2050. The largest shares of this reduction are assigned to material efficiency (24 megatons) and the reuse of buildings components (20 megatons). Prolonging building lifetime is expected to have a significant effect after 2050 [42].

The most recent publication by the International Resource Panel identified a GHG emission reduction potential of 35% to 40% for residential buildings based on increased material efficiency. The main contributor is a more intensive use of the buildings. This means increasing construction of multi-family rather than single-family houses [15].

### 2.3. Research Method

To answer the research questions, this study applied an application-oriented adaptation of the policy mix concept described in [56]. The policy mix concept has been widely applied to assess energy and sustainability transitions with a focus on policy evaluation [56–58]. It is considered the most suitable for our purpose, as it considers the interlinkage between policies and overarching goals implementing a broader perspective. At the same time, it can be adapted to specific applications depending on the research question [59]. The approach and its implementation are described in the following paragraphs.

The policy mix concept consists of three buildings blocks (elements, policy process and characteristics) and their dimensions. These dimensions comprise policy field, governance level, geography and time [56]. We limited the dimensions in the following way (see also Figure 1):

- The policy field is limited to the legal framework addressing the CE;
- The governance level is limited to horizontal instruments (i.e., instruments established by entities on the same governance level);
- The geographic coverage is limited to the EU;
- The time dimension is limited to the present (i.e., only the legislative framework currently in effect is covered, while future initiatives are excluded from the analysis).

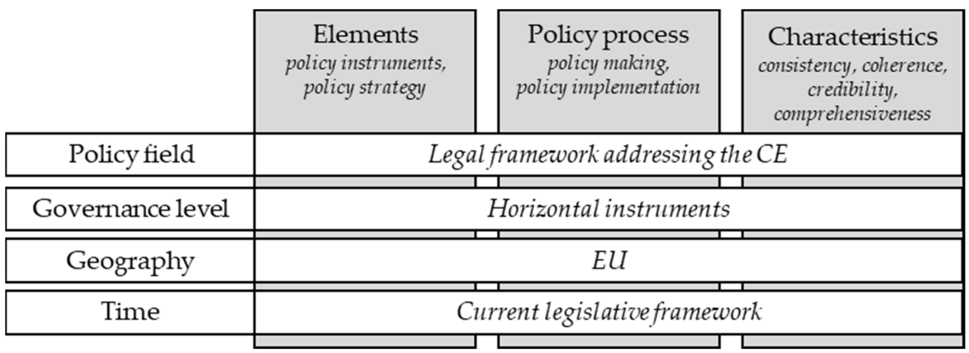


**Figure 1.** Dimensions of the policy mix considered in this contribution, adapted from [56].

The first building block covers the elements of the policy mix. Two types of elements can be differentiated: policy strategy and policy instruments [56]. The policy strategy considered in this paper derives from the European Green Deal and the CEAP described in the introduction.

To identify the policy instruments, we conducted desk research of the EU legal framework with two focal points. On the one hand, we identified the legal framework focusing on CE, starting from the new CEAP as well as the Commission Staff Working Document, *Sustainable Products in a Circular Economy—Towards and EU Product Policy Framework contributing to the Circular Economy*, which is related to the initial CEAP [3,59,60]. On the other hand, we supplemented this research by analyzing the product-specific legal framework for batteries and buildings in the EU. This framework does not necessarily focus on CE aspects, but often defines standards that are relevant in the context of a CE (e.g., design or material criteria) [61]. These documents have a strong product focus, which is reflected in the subsequent analysis.

Consequently, the product delimitations are crucial for including or excluding specific instruments. Due to the described differences between the value chains, the delimitation for batteries and buildings varies. For batteries, we covered battery systems as well as products containing batteries. The materials used in batteries are not included. For the building value chain, we exclusively considered buildings and building materials. Technical building systems were not included. These systems differ fundamentally from buildings and building materials in terms of materials and lifetimes and would require a separate analysis, which was beyond the objective of this article. Due to the different product delimitations, a challenge arises in the analysis. While batteries can be assumed to have a lifetime of 5 to 15 years [62], the lifetime of buildings and building materials differs significantly. Buildings have a long service life (~80 years). However, building materials have shorter useful lives and must be replaced before the end of a building's life [52]. A separate analysis was conducted for each value chain mentioning this aspect if relevant.

Table 5 presents an overview of the identified instruments forming the legal framework and thus the prerequisites for CE. We adapted the typology of instruments introduced by Rogge and Reichardt in [56]. As already stated in the introduction, our assessment focused exclusively on the legal framework and therefore did not need to differentiate instrument type (economic instruments, regulation and information) or instrument purpose (technology-push, demand-pull or systemic), as all instruments can be assigned to demand-pull. Instead, a distinction is made between the value chain (all, battery or building) and the legal type as defined by the EU [63]. Section 3 describes the elements of the policy mix.

**Table 5.** Overview of the considered instruments.

| Value Chain | Instrument Title | Legal Type |
|---|---|---|
| All | Ecodesign | Directive |
| | Energy Labeling | Regulation |
| | Ecolabel | Regulation |
| | Green Public Procurement | Communication |
| | EPR/WFD | Directive |
| | Regulation on Registration, Evaluation, Authorization and Restriction of Chemicals | Regulation |
| | Biocidal Product Regulation | Regulation |
| | Regulation on Persistent Organic Pollutants | Regulation |
| Batteries | Battery Directive | Directive |
| | Proposed Batteries and Battery Waste Regulation | Regulation |
| | End-of-life Vehicle Directive | Directive |
| | Directive on Waste Electrical and Electronic Equipment | Directive |
| Building | Energy Performance of Buildings Directive | Directive |
| | Construction Products Regulation | Regulation |
| | Eurocodes | Regulation/Directive |

The second building block covers the policy process. This building block comprises the analysis of the policy making and policy implementation as well as the style of both. The policy process, as determined by actors and events, can significantly influence the efficiency of policy instruments [56]. Due to the limitation of the time dimension to the current legal framework, the policy process was not assessed in detail. Instead we focused on the differences between the policy processes addressing the two value chains.

The third and last building block comprises the characteristics of the identified elements (consistency, coherence, credibility and comprehensiveness). This is the most relevant building block because it is used to determine the efficiency of the assessed elements [56]. The first two criteria are also considered in policy studies as their relation characterizes the policy process and depicts its dynamics [58]. Consistency describes how the instruments are aligned to each other, while coherency refers to the heterogeneity of the policy process [56]. Kern et al. describe four typical characteristics of policy processes which can be derived from these two criteria in [58]. Table 6 presents an overview.

**Table 6.** Relationship of consistency and coherence as shown in [58].

| | Consistent | Inconsistent |
|---|---|---|
| **Coherent** | Replacement: conscious effort to restructure goals and instruments by sweeping aside the old mix and designing a new one from scratch | Conversion: instruments evolve while the old goals are retained |
| **Incoherent** | Drift: changing policy goals without changing the instruments used to implement them | Layering: adding new policy goals and instruments to the mix without discarding previous ones |

Where possible, we considered the third criterion, credibility, based on a literature research. As described in [56], analyzing credibility is challenging. The authors propose either analyzing the impact of policies or gathering information from stakeholders. Since both are beyond the scope of this study, we refer to the results of existing analyses if relevant.

The final criterion, comprehensiveness, was analyzed in more detail by assessing the value chain as a common structure as well as other aspects relevant for a CE. The individual aspects were grouped according to the described value chain stages, and there are overlaps between them, which were deliberately chosen to ensure the exhaustive identification of CE prerequisites.

In practice, this procedure was implemented by searching the legislative documents using specific search phrases. If an aspect was found in the document, the context was checked for plausibility in order to exclude misinterpretations. The following CE aspects and related search phrases (in brackets) were used:

- Durability (durab);
- Reusability/Upgradability/Reparability (re-us/reus/upgra/repa);
- Recycling/Remanufacturing (re-cycl/recycl/re-manufactur/remanufactur);
- Resource Efficiency (efficien);
- Energy Efficiency (efficien);
- (GHG) Emissions (emission);
- Hazardous Chemicals/Dangerous Substances (hazard/danger);
- Carbon Footprint/Environmental Footprint (footprint);
- Critical Sourcing (critical).

The results of the analysis were summarized as a two-dimensional mapping, where the value chain stage is displayed horizontally and the CE aspects vertically. The instruments implementing the legal framework were specified by a short designation. Additionally, a pictogram indicates the product delimitation and the type of legal requirement. The latter enables the further differentiation of the instruments into minimum, informational and voluntary requirements.

Based on the two-dimensional mapping, two types of gaps can be identified: horizontal and vertical gaps. Horizontal gaps describe gaps in the coverage of the value chain stages, and vertical gaps describe gaps in the coverage of CE aspect. The identified gaps were subsequently discussed in relation to the described CE potentials along the value chains. Based on this, we assessed the relevance of the identified gaps and thus the comprehensiveness of the prerequisites. Finally, we identified necessary improvements during this analysis.

Particular attention was paid to comparing the results for both value chains. Our aim was to develop recommendation for how to improve the prerequisites along the building value chain based on the identified characteristics and the policy process.

## 3. Results

The CE has gained momentum in the current policy strategy of the EU. The European Commission put CE on the political agenda with the first CEAP in 2015 [59]. Subsequently, it was identified that a legal framework is needed for circular value chains [60]. In light of the European Green Deal, the CE has gained even more relevance for mobilizing industry [1]. A new CEAP was published in 2020 and the demand for a legal framework for key value chains was highlighted [3]. The current horizontal instruments at the EU level addressing these value chains are:

- Ecodesign;
- Energy Labeling;
- Ecolabel;
- Green Public Procurement (GPP);
- EPR mentioned in WFD [20,60].

The Ecodesign Directive and the Energy Labeling Regulation cover energy-related products. The implementing directives or regulations specify the product requirements based on these frameworks [64,65]. While the Ecodesign Directive allows product requirements to be set along the entire value chain [64], in the past, product requirements focused mostly on energy efficiency during the use phase. In more recent implementing measures, the requirements also cover CE aspects (e.g., the requirements relevant for recycling or reparability). The CE requirements vary from mandatory information for disassembly to minimum design requirements for recycling [66]. The Sustainable Product Initiative (SPI) has ambition to widen the scope of the Ecodesign Directive and to set requirements in order to reduce their environmental impact, the expected requirements will foster among other circular economy [67]. In contrast, the implementing regulations for Energy Labeling exclusively set informational requirements for CE—with a focus on energy efficiency—during use [65].

In addition to these mandatory instruments, the Ecolabel Regulation and GPP are voluntary instruments strengthening the EU's CE framework [68,69]. Theoretically, the Ecolabel Regulation can cover all products, but product requirements have to be specified via decisions, e.g., by the European Commission [63,68]. The requirements for the Ecolabel vary from the minimum requirements on raw material use to product design for repair and recycling, and therefore encompass the entire value chain [70]. In the context of a CE, these requirements are more ambitious than Ecodesign and Energy Labeling. Nevertheless, the Ecolabel has had a low impact on transforming the value chain: only a few products comply with the Ecolabel, their market share is relatively low and the impact of this type of label on buying decisions has also been reported as low [71,72].

Similar to the Ecolabel, GPP criteria are more ambitious than the mandatory requirements of Ecodesign and Energy Labeling. GPP is based on a Commission Communication from 2008, highlighting the potentials of sustainable public procurement and focusing on typical public procurement areas (e.g., paper or furniture) [69,73]. Unlike the instruments mentioned above, GPP is not legally binding [69], so the GPP criteria are usually published as recommendations.

In contrast to the product-specific or value chain-specific instruments mentioned, the WFD addresses two value chain stages for several products and materials. The recycling and recovery/disposal of materials is regulated, e.g., by defining recycling quotas. Another approach to increase the circularity of products and materials is the EPR described in the WFD. EPR states that the responsibility for a product remains with the producer even during the later stages of the value chain [20]. This is challenging for products with a long service life. The WFD is supplemented by additional product-specific regulations that address the last two value chain stages, e.g., the End-of-Life Vehicle Directive (ELVD) or the Directive on Waste Electrical and Electronic Equipment (WEEE) [74,75].

The other instruments that address the raw material stage focus on the use of substances and materials that can be harmful to the environment or human health. These include the Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), the Biocidal Product Regulation (BPR) and the Regulation on Persistent Organic Pollutants (POPs) [76–78]. A similar but product-specific approach can be found in the Directive on the Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS) [79]. Although these are not specifically mentioned in the context of the CE [60], their relevance is presented by the selected CE aspects [3].

For a more in-depth analysis of the value chains, the characteristics of these instruments and other product-specific instruments are described in the following sections.

### *3.1. Prerequisites along the Battery Value Chain*

Compared to the building value chain described in the following section, fewer instruments cover the battery value chain. The general legal framework described above is not relevant for this value chain. Even though it would be possible to cover batteries under Ecodesign and Energy Labeling [37], no regulation has been implemented that focuses explicitly on batteries. No criteria relating exclusively to batteries have so far been set within the framework of Ecolabel or GPP [70,80]. REACH only covers chemical substances of batteries and not batteries as a whole [81]. Furthermore, batteries are not covered by general instruments, such as WFD or RoHS. Instead, there is a value chain-specific instrument, the current Battery Directive (BD) [20,79,82].

The BD came into force in 2006 and aims to cover the entire battery value chain, although, it focuses on limiting hazardous substances during the raw material stage and the collection and recycling of batteries after use. The disposal of batteries in landfills or by incineration is prohibited and recycling is the only option after use. The BD requires a recycling efficiency of 50% to 75% by average weight, without specifying which materials should be recovered [82]. To address the various challenges along the entire value chain, the EU proposed a new Batteries and Battery Waste Regulation (BWBR) [35] in December 2020, which sets out ambitious CE actions and specifically addresses EV batteries.

For example, the proposed BWBR determines mandatory recycled contents during the raw material stage and addresses durability, reparability and energy performance during the use stage as well as the recycling efficiency during recycling. The BWBR stands out as it requires information about the carbon footprint throughout the value chain, and includes performance classes for the carbon footprint as well as maximum carbon threshold. It also requires a mandatory supply chain due diligence [35]. A product passport to include required information is commonly mentioned in relation to the BWBR. Based on the new CEAP, the proposed BWBR can act as a guideline for instruments supporting the transition to circular value chains [3].

In addition to these battery-specific instruments, two other relevant instruments address waste products including batteries. The first is the ELVD. This directive addresses waste from vehicles and aims to reduce, recycle and dispose of waste, and to improve the design to facilitate dismantling, re-use, recovery and especially recycling. Batteries are covered to ensure their removal from the vehicles and safe handling before recycling [74]. The second instrument is the WEEE, which aims to reduce the impacts of waste from electrical and electronic equipment. Similar to the ELVD, batteries are covered to ensure their removal before recycling and disposal [75].

Due to the small number of instruments and the targeted coverage of the entire value chain, it is possible to determine the consistency of the policy mix addressing CE along the battery value chain. Moreover, the proposed repeal of the BD by the BWBR indicates a coherent policy process following Kern et al. (see Table 6) [58]. This can be attributed to the homogeneity of the value chain, the historical development, but also the prospective relevance of the value chain. Furthermore, batteries are traded globally so that upstream instruments are common to ensure the competitiveness of producers from the EU.

As the BWBR is currently only a proposal, its credibility cannot be confirmed. However, the stakeholder consultation and impact assessment as well as the ex-post evaluation of the BD suggest credibility [35]. The requirement type also indicates the credibility of the legal framework as mostly minimum and informational requirements are in place.

The comprehensiveness of the policy mix is shown in Figure 2 and compared to the CE potentials described in Section 2.1. The overall aim of the CE along the battery value chain is to reduce the demand for primary raw materials. This is important, given the prospectively increasing demand for several materials, including cobalt and lithium.

During the raw material stage, using secondary materials can lower the demand for primary materials. Even though this is covered by the BWBR, this CE action is challenged by the availability of secondary material. Thus, the BWBR defines supporting actions during the recycling stage.

A horizontal gap during processing/manufacturing can be identified, as it is exclusively covered by informational requirements. This is due to a lack of CE potentials during this stage. This is therefore not a gap in the prerequisites for CE, but is caused by the characteristics of this value chain.

Several CE actions to intensify use can be implemented during the use stage. Among others, increasing reparability and durability can lower the demand for raw materials. Additionally, a second life of batteries should be targeted in order to increase the circularity of this value chain. Those aspects are covered by the proposed BWBR.

All the CE potentials during recycling are addressed by the proposed BWBR with the exception of the aforementioned battery passport. The recycling efficiencies and collection targets are defined to support the use of secondary materials in the raw material stage. The battery passport is currently not mandatory, although it could further increase the recycling efficiencies, as described in Section 2.1.

The recovery/disposal stage seems underrepresented at present, but this is caused by the prohibition of battery disposal without treatment and recycling. Nevertheless, this stage is covered by the EPR.

The proposed BWBR addresses a wide range of CE aspects. This confirms our initial assumption concerning the relevance of the BWBR as a benchmark for CE policies. Vertical gaps can be identified, especially for resource efficiency. However, this overlaps with the other CE aspects covered sufficiently. At first glance, another vertical gap can be identified for the (GHG) emissions. However, this aspect overlaps with the carbon/environmental footprint, which is covered adequately.

When considering the 9R framework, the prerequisites proposed by the BWBR for the exploiting the CE potentials along the battery value chain are appropriate. The mandatory establishment of a battery passport can further improve the legal framework.

In conclusion, the consistency and coherency of the policy mix along the value chain stages and the product focus address relevant CE aspects in a targeted manner. On closer inspection, however, it becomes clear that this is mainly due to the proposed BWBR, which has a very holistic approach.

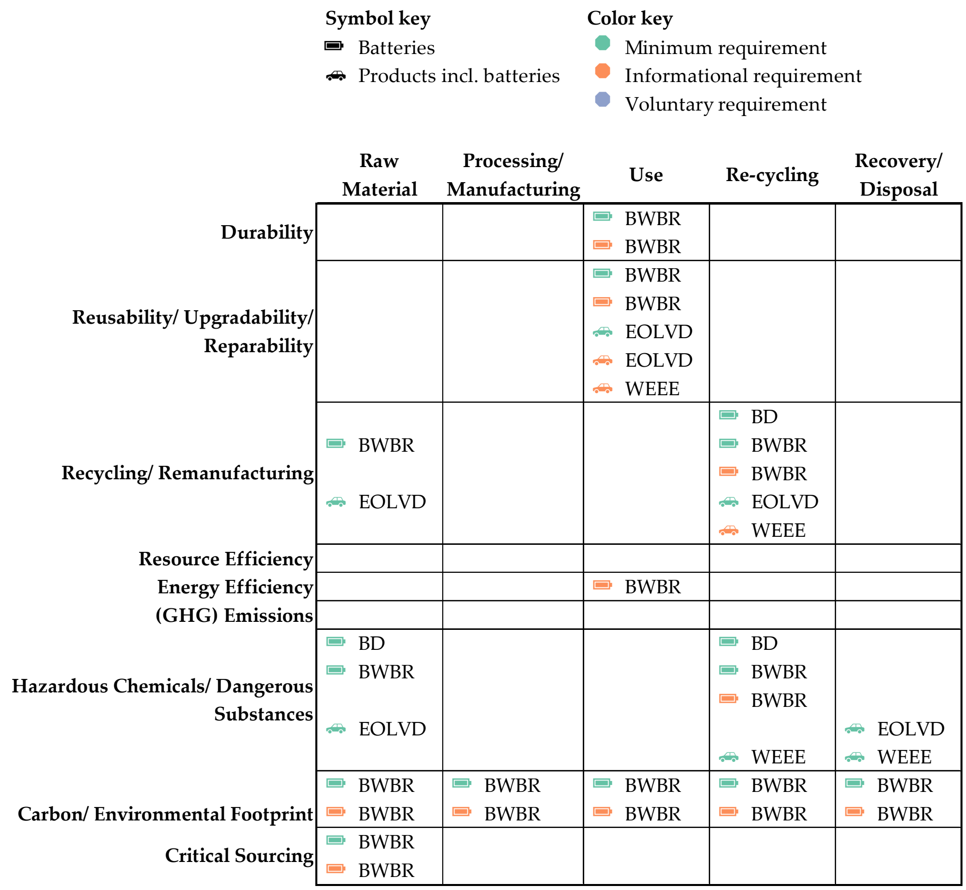


**Figure 2.** Mapping CE prerequisites for the battery value chain.

### *3.2. Prerequisites along the Building Value Chain*

Various instruments cover the building value chain or the products related to this value chain. As the Ecodesign and Energy Labeling implementing measures currently only cover technical building systems, they are not considered in this study. Building components, such as windows or insulation materials, do fall under energy-related products, but no implementing measure has been applied to them so far [83,84].

Some building materials are already covered by Ecolabel decisions for hard coverings and floor coverings. In these decisions, specific requirements are defined to extend the durability and enable the repair and reuse of the components in the use stage. Recycling requirements are also determined. Further requirements cover the emissions to air during processing/manufacturing and use. The use of hazardous substances is addressed for the raw material stage by either limiting or restricting their use. The critical sourcing of materials is covered by verifying the legal sourcing of raw materials for floor coverings [85,86].

In contrast to the component-specific or material-specific perspective of Ecodesign, Energy Labeling and Ecolabel, building-specific criteria are formulated in the context of GPP. As previously mentioned, these cover a significantly longer service life. The criteria cover office buildings on the one hand and roads on the other hand. In general, the type of criteria are similar to the Ecolabel criteria. They cover durability, reparability and reusability during use as well as recycling. The GPP criteria also cover aspects, such as resource efficiency during processing/manufacturing, and energy efficiency during use. The GPP stands out for the building value chain due to the consideration of GHG emissions along the complete value chain. The use of hazardous substances is addressed during the use stage as well as during recovery/disposal by ensuring safe handling. The sourcing of critical raw materials is considered exclusively for office buildings and the use of timber for their construction [87,88].

The building value chain is also covered by the WFD, which specifically mentions the reduction and recycling of construction and demolition waste. It also theoretically covered by the EPR. In practice this is challenging due to the long lifetimes of buildings. Consequently, this framework is not yet adequate to bring about the desired material reduction and recycling [20,89]. Even though the building value chain is also covered by the raw material-centric instruments REACH, BPR and POPs, no building-specific requirements are formulated [76–78].

In addition to these CE-related instruments, the building value chain is additionally covered by three relevant sector-specific instruments: the Energy Performance of Buildings Directive (EPBD), the Construction Products Regulation (CPR) and the Eurocodes [90–92]. As the name suggests, the EPBD determines criteria for the energy efficiency of buildings during the use phase. In addition to the building as a whole, this covers the technical systems and the building envelope, and is thus within the scope of this study [90].

The CPR, in contrast, does not focus on buildings as a unit but on the materials or products used for construction. Thus, the CPR covers many different products and determines the diverse requirements for these [93]. These requirements are implemented as mandatory product specific standards. While the framing regulation allows the complete coverage of the value chain, this is not necessarily implemented in the standards [91]. Similar to the CPR, Eurocodes define standards for the structural design of buildings in the EU [92]. An evaluation is beyond the scope of this article due to the large number of standards.

In addition to the described instruments, three other initiatives are worth mentioning for CE along the building value chain: the Circular Plastics Alliance (CPA), Level(s) and a technical study on digital building logbooks. The CPA is an initiative, including industrial, public and academic stakeholders, which aims to create markets for recycled plastics. Plastics from construction is one of the key areas addressed by the initiative [94]. The Level(s) framework provides common sustainability indicators for buildings, and is therefore a promising approach to obtain an overview of the transformation to a more circular building value chain [95]. The tender for a technical study on digital building logbooks (similar to the product passport for batteries) addresses the challenges posed by the diversity of products and materials along this value chain [96].

In contrast to the policy mix analyzed for batteries, these instruments were found to be inconsistent and the policy process incoherent. The value chain is covered by diverse instruments with varying focal points, as described in the preceding paragraphs. In contrast to the battery value chain, the trade of building materials is less relevant. Thus, there is less demand for upstream regulations on raw materials and processing/manufacturing. At the same time, the described historical development and importance of the sector as well as the high diversity of products related to this value chain have resulted in an incoherent policy process, as changing policy goals have not been taken into account. This can be traced back to changing functional requirements and assessments of toxicity, for example. Thus, it is also more common to address components or materials rather than buildings. Only newer or more ambitious instruments focus on buildings as an end-use good. According to Kern et al., this relationship can be described as "layering"; new instruments have been introduced without revising or discarding existing ones [58].

The longer existence of the legal framework along the building value chain should theoretically make it easier to examine its credibility. The challenge here is due to the large number of instruments that have not (yet) been evaluated as a whole. However, an evaluation of the legal framework addressing the use of sustainable building materials has shown that the inconsistency of the legal framework leads to uncertainty among stakeholders [97]. The analysis of the WFD and construction and demolition waste by Zhang et al. cited above, also revealed the inadequacy of the directive for exploiting CE potentials during the recycling and recovery/disposal stages [89]. In the context of policy evaluations, approaches that take a value chain perspective rather than a stage-specific one seem to be more promising [98].

In contrast to the battery value chain, the high number of voluntary requirements along the building value chain comprise an additional challenge to its credibility. Only the use and the recycling stages are covered by minimum and informational requirements. Energy efficiency, in particular, should be mentioned during use, as the EPBD was established for this purpose only. This can be attributed to the economic aspect here, since energy efficiency improvements often lead to cost reductions for users. In contrast, the actions related to the other CE aspects mentioned can potentially increase the costs.

The comprehensiveness of the policy mix along the building value chain is shown in Figure 3 and compared with the CE potentials described in Section 2.2. The CPR and Eurocodes are not shown in this depiction, for the reasons outlined above. When considering the building value chain and the related CE potentials, it is apparent that the key impact of CE is to reduce the demand for energy-intensive intermediates, such as cement and steel, because of their high energy demand and GHG emissions during the manufacturing stage. As described, this can be implemented by increasing material efficiency, using secondary materials or material substitutes.

The use of alternative materials with less impact (e.g., secondary materials or material substitutes) can reduce the demand for energy-intensive intermediates. Even though recycling is addressed by the WFD, the use of secondary materials and raw materials from other sources is not mandatory along the building value chain, which indicates a horizontal gap. This is especially the case for the use of material substitutes. It has to be mentioned that these substitution potentials are limited by the availability of substitutes.

Increasing material efficiency during the design stage directly affects manufacturing/processing by significantly reducing the material demand. Nevertheless, the mapped legal framework shows a horizontal gap here. In addition, this CE potential is not mentioned in the CEAP. A possible starting point to increase material efficiency is to reduce over-specification, which could be addressed by the CPR and Eurocodes.

Another relevant CE potential is to intensify the use of buildings by optimizing the use of space and extending the lifetime, e.g., by repurposing. Overall, intensifying the use of buildings has the highest CE potential and, according to the 9R framework, the highest implementation priority during use. Despite this, we identified a horizontal gap in the current legal framework as the majority of instruments address energy efficiency. Even though durability and reusability are addressed by the WFD in general, there are no specific requirements for extending the useful lifetime of buildings.

As described, the building value chain for recycling is covered by determining recycling quotas for construction and demolition waste. Those quotas are not sufficient [89] and do not consider whether the material is recycled for an equivalent use case. Thus, the risk of downcycling is not addressed systematically and the building value chain remains close to linear. Additionally, there are missing collection requirements for recycling of building materials and especially steel.

Another horizontal gap can be identified for the recovery of construction and demolition waste for other purposes during the recovery/disposal stage.

While the voluntary GPP criteria cover the widest range of CE aspects, the mandatory vertical coverage is limited to reusability/upgradability/reparability, recycling/remanufacturing and energy efficiency.

The legal framework currently focuses on recycling, which has a low priority according to the 9R framework. Thus, the building value chain remains close to a linear economy. The more ambitious criteria of Ecolabel and GPP as well as the sectoral challenges suggest that, further requirements have to be determined. During the raw material stage, quotas for the use of recycled or low impact materials should be defined, while design standards should be enhanced to ensure a circular design. In this context, it is particularly important to create sales markets through material utilization quotas. Furthermore, building use should be intensified through either longer or more intensive use. Overall, the building value chain is challenged by the high diversity of products and related lifetimes. Initiatives, such as Level(s), and the digital building logbook are promising tools to enable a more targeted assessment of this value chain.

In summary, the described inconsistency and incoherency of the legal framework leads to insufficient coverage of CE along the building value chain. This is caused by a varying focus on value chain stages and CE aspects as well as the high share of voluntary requirements.

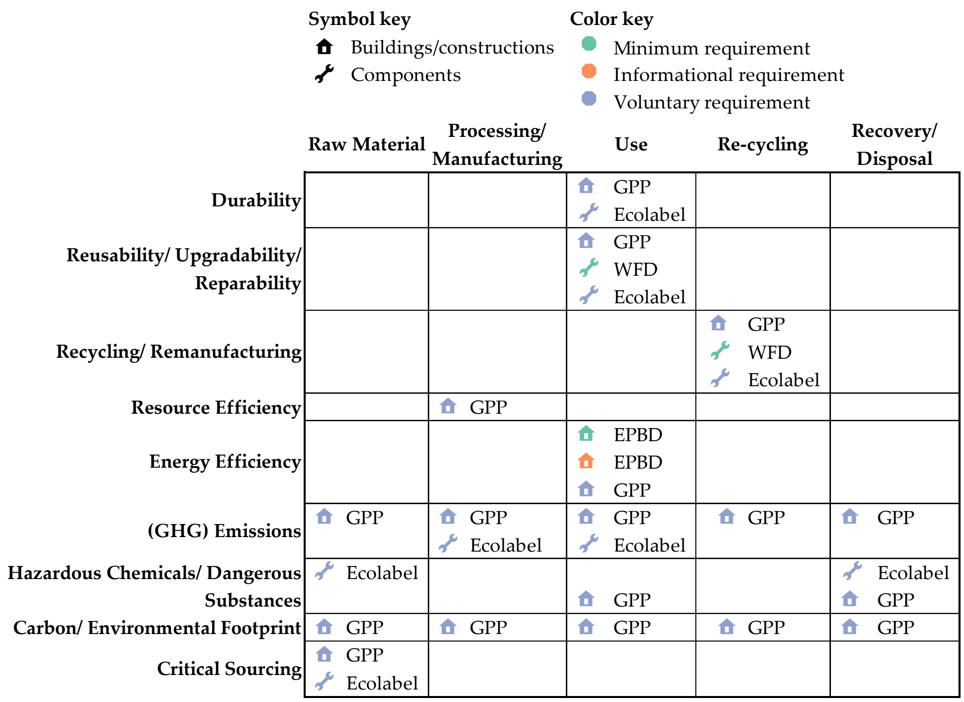


**Figure 3.** Mapping the CE prerequisites for the building value chain.

## 4. Discussion

As shown in the preceding section, the legal frameworks for CE differ in the battery and building value chain in terms of efficiency. This can be partly explained by the different temporal dimensions of the development of the legal framework and the sectoral characteristics of the two value chains. The framework for the battery value chain provides more adequate prerequisites for the transition to a CE based on the proposed BWBR. Even though this regulation is not yet in force, it is used as a benchmark for instruments facilitating CE in the EU in the following discussion. Although the overall aim of the CE and the product's lifetime differ between the value chains, the general approach of the BWBR can be transferred to the building value chain. We used the policy mix concept to compare the prerequisites along both value chains.

While the policy strategy covering the value chains is the same, there are apparent differences regarding the relevant instruments and their characteristics. The battery value chain is characterized by consistent policies and a coherent policy process (replacement). The building value chain, in contrast, is covered inconsistently by an incoherent policy process (layering) [58]. Due to the contradictions along the building value chain, the credibility of the policies is also limited. Consequently, the further development of the legal framework along the building value chain should aim to align the policy instruments and policy goals to achieve replacement (consistent policy instruments and coherent policy process) [58]. Its credibility can be further improved by implementing mandatory rather than voluntary requirements.

When improving the consistency, coherency and credibility of the legal framework for the CE along the building value chain, comprehensiveness should not be neglected as a criterion. As described in [98], a perspective that considers the entire value chain is more promising than focusing on one or more stages. This also applies to the legal framework for the CE along the battery value chain. While a completely new legal framework for buildings is not realistic, existing and new instruments should be better aligned. It is important to consider complementary instruments when doing so, as well as the sector-specific CE potentials and the 9R framework. The preceding section presented one way this can be done for the building value chain.

Even though we did not assess the implementation of the legal framework, this is still relevant. In addition to the horizontal instruments described above, the vertical instruments for implementation in the EU Member States and the practices related to QI affect the efficiency of a policy mix. Further analysis of the policy process, including the actors involved, can also be helpful to improve the legal framework. The multi-level governance approach can be used for this purpose as described in [57].

## 5. Conclusions

Overall, we found that the prerequisites differ for exploiting the CE potential along the battery and building value chains. This can be explained by the different aims of a CE for the two value chains, their different characteristics and the varying efficiency of the legal framework. The battery value chain stands out due to a highly efficient and targeted legal framework. In contrast, the legal framework covering the building value chain lacks consistency, coherency, credibility and comprehensiveness. By comparing the two value chains, conclusions can be drawn for how to improve the legal framework along the building value chain. It is very important, to interlink existing and new instruments to replace the existing policy mix rather than layering them. Furthermore, it can be useful to develop a specific legal framework for the building value chain, similar to that for batteries. This approach would define the CE requirements for each stage, making it possible to exploit the CE potentials from material efficiency, recycling and material substitution.

A multi-level governance approach that considers policy implementation and practices related to QI could enhance this paper's results. Such an assessment should be repeated as soon as the other QI elements related to the CE have been introduced into the two value chains.

In general, the results can also be transferred to other key value chains identified in the new CEAP. Thus, determining the relevant instruments and value chain-specific requirements is useful for the relevant key sectors. This should take into account the different aims of CE for different value chains as well as the 9R framework. This would enable the legal framework to fulfill the described characteristics of consistency, coherency, credibility and comprehensiveness in the context of a CE. Both general frameworks and value chain-specific instruments are required to fully exploit the CE for every product.

Overall, it is necessary to quantify the impact of the mentioned instruments on the key sectors in order to support the further development of the legal framework. While sufficient prerequisites have already been proposed for the battery value chain, the building value chain is of further interest, not least because it is such a relevant sector in terms of carbon reduction.

**Author Contributions:** Conceptualization, M.T.L., R.B., A.H., M.P. and A.D.; methodology, M.T.L. and M.P.; investigation, M.T.L., R.B., A.H. and M.R.; writing—original draft preparation, M.T.L., R.B., A.H. and M.P.; writing—review and editing, M.T.L., R.B. and A.D.; visualization, M.T.L. and R.B. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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