INTERNATIONAL DESIGN CONFERENCE – DESIGN 2024
https://doi.org/10.1017/pds.2024.153

# Towards a unified absolute environmental sustainability decoupling indicator

Manon Villers [1,2,✉], Daniela C. A. Pigosso [1,2], Thomas J. Howard [3] and Tim C. McAloone [1,2]

[1] Technical University of Denmark, DTU Construct, Denmark, [2] Technical University of Denmark, Centre for Absolute Sustainability, Denmark, [3] Technical University of Denmark, Centre for Technology Entrepreneurship, Denmark

✉ mchvi@dtu.dk

**Abstract**

Manufacturing firms are facing the critical need to manage their business growth while staying within the biophysical limits of the planet. Absolute environmental sustainability decoupling (AESD) combines these goals and is one of the keys for manufacturing firms to achieve their sustainable transition. This study offers an initial contribution to categorise decoupling at the firm level while incorporating absolute environmental sustainability goals. It also explores the role of design in achieving AESD and opens doors for further research on manufacturing firms' sustainability transition.

*Keywords: absolute environmental sustainability, decoupling, manufacturing firm, ecodesign, design strategy*

## 1. Introduction

In response to the pressing planetary crisis, manufacturing firms are trying to decrease their environmental footprint, whilst staying competitive. In other words, they aim at decoupling their business growth from their environmental impacts and resource use. Decoupling implies that the link between environmental "bads" and economic "goods" should be broken, if firms are to grow whilst achieving their environmental sustainability targets (OECD, 2002). One of the strategies implemented by manufacturing firms to simultaneously decrease their environmental impacts and increase their profitability and/or competitive advantage is ecodesign (Pigosso and McAloone, 2017; Plouffe *et al.*, 2011). Ecodesign focuses on reducing the environmental footprint of a product throughout its entire life cycle, whilst ensuring that essential product criteria such as performance and cost are not compromised (Johansson, 2002).
However, nowadays, companies are not only trying to reduce their environmental footprints, but they are also trying to reduce their impacts below absolute thresholds by setting Science-Based Targets (SBTs) - mainly for climate change (SBTi, 2023a). SBTs are means to decrease companies' environmental impacts under the Earth's environmental boundaries (Bjørn *et al.*, 2022), which define the limits that constrain resource use and the planet's ability to handle emissions and toxicity (Richardson *et al.*, 2023). Integrating absolute boundaries at the corporate level is part of the shift from relative incremental sustainability practices to operationalising absolute environmental sustainability (AES) at the firm level (Ryberg *et al.*, 2018).
When applying the lens of AES, both the decoupling theory and ecodesign practices need to be enriched, and firms should aim at decoupling within the ecological boundaries (Vadén *et al.*, 2020). There are few studies in the literature studying decoupling within a framework of AES (Haberl et al., 2020). This new perspective on decoupling raises several questions. First, companies' ambitious business growth targets

make the achievement of SBTs even more difficult, as increasing business growth usually leads to the consumption of more resources and energy, resulting in environmental impacts increase (Otero *et al.*, 2020). This is also accentuated by the fact that decoupling within the ecological boundaries has been proven not to have any empirical foundation at the global level (Haberl *et al.*, 2020; Parrique *et al.*, 2019; Wiedenhofer *et al.*, 2020). Moreover, thus far, the decoupling theory has mainly been developed at the macroeconomic level, i.e., at the global, country or sectorial levels of society, and there is limited literature on decoupling at the firm levels (Wiedenhofer *et al.*, 2020). Finally, the literature on AES has focused chiefly on how to downscale the planetary environmental limits to smaller entities such as individuals, organisations, sectors, nations, etc. (Wegge Hjalsted *et al.*, 2020) but it still lacks elements concerning how to translate it at operational levels (Aurich et al., 2022; Moshrefi et al., 2020). Understanding the implications of an AES perspective on corporate decoupling would be a contribution to the operationalisation of AES.
This paper aims at (1) defining Absolute Environmental Sustainability Decoupling (AESD) at the firm level, based upon the integration of decoupling within a framework of AES; and (2) exploring the role of design in achieving AESD by taking one example - how ecodesign strategies could help manufacturing companies in achieving AESD. To do so, the decoupling definition is downscaled from the macro to the firm level through a literature review. And then, the consolidated definition of AESD is used to analyse ecodesign strategies. Section 2 describes in detail the methodological approach adopted and is followed by the results (Section 3), discussion (Section 4) and conclusion (Section 5).

## 2. Methodological approach

The paper first defines AESD at the firm level in a two-step process: examining decoupling at the macro level through an AES lens and then scaling it down to the firm level (Section 2.1). Secondly, it explores the potential of ecodesign strategies in achieving AESD for manufacturing firms (Section 2.2).

### 2.1. Decoupling categorisation from the macroeconomic to the firm level

The first step consisted in consolidating a definition of AESD at the macroeconomic level. A literature review was conducted focusing exclusively on reviews tackling decoupling of economic growth and environmental pressures at the macroeconomic level and on analyses taking the perspective of AES. The search string used in Scopus is available in Appendix A. The main inclusion criteria were to limit to reviews including a perspective of AES. However, AES was not included directly in the search string because the term is not yet widely used. Reviews that mentioned impact reductions with quantified absolute environmental thresholds were considered taking a perspective of AES. From this first step, two reviews were identified - one of them is split into two articles: Haberl et al. (2020); Wiedenhofer et al. (2020) and Vadén et al. (2020). Snowballing allows to identify another review from Hickel and Kallis (2019). Finally, a search into the publications from different organisations led to a last review from Parrique et al. (2019).
The reviews were then analysed and compared according to several criteria, including their approach, how they categorise decoupling and how they define decoupling aligned with AES. Decoupling can be defined and measured differently (Parrique *et al.*, 2019), these differences are encompassed within several parameters and their respective values, called parameters' degrees. They were identified for each review; many of the parameters described the same ideas but had different names, so these were clustered into nine groups. Finally, each group was named and given a definition. A similar process was followed to consolidate the degrees of each parameter. The reviews described two degrees for each parameter, an unsatisfying degree and a satisfying degree corresponding to a decoupling aligned with AES. All the parameters and their degrees consist of the decoupling categorisation. The definition of AESD corresponds to achieving all the satisfying degrees.
The second step consisted of downscaling the decoupling categorisation from the macro level to the firm level. To do so, the macro level decoupling categorisation was adapted to the firm context. Each parameter of the categorisation was taken and adapted by raising three questions: “Does this parameter exist at the firm level?”, “Are the variations of the parameters the same at the firm level?”, and finally “Are there any other parameters that could be relevant at the firm level?”. This resulted in a categorisation with eight parameters. From the macro level categorisation, two parameters were suppressed, one was completely transformed, and one was added. The other parameters were slightly



https://doi.org/10.1017/pds.2024.153 Published online by Cambridge University Press

adapted to fit the firm context. This first draft of the categorisation at the firm level was consolidated by discussions with experts from relevant fields (circular economy, product-service systems, quantitative sustainability, and business development). Discussions took the form of semi-structured interviews that aimed at verifying the relevance, completeness, and clarity of the parameters of the categorisation. This round of evaluation led to some adaptation of the categorisation and adjustments in the wording of the parameters. The decoupling categorisation at the macro level and the detailed explanation of how the parameters were downscaled to the firm level are available in Appendix B.

### 2.2. The role of design

The last step of the methodology for this study entailed the exploration of the role of design in achieving AESD in manufacturing firms. To do so, six ecodesign strategies were taken from McAloone and Pigosso (2020) and Vezzoli and Manzini (2008) and their influence on AESD was explored by identifying examples and using the parameters from the decoupling categorisation. To ensure a diverse range of examples, literature, company cases and discussions with experts were used as sources. Three elements were investigated to understand the role of ecodesign strategies at the product/service level in fostering the achievement of AESD. First, how each ecodesign strategy can support AESD was explored. Thereafter, it was analysed, whether the ecodesign strategies could be deemed sufficient enough to encompass the AES dimension of decoupling. Finally, examples were curated to illustrate how the ecodesign strategies may even undermine AESD. From this exploration, several principles were highlighted to understand the variables influencing to what extent ecodesign strategies influence positively or negatively decoupling.

## 3. Results

This section presents the various results of the study. First, it gives a brief overview of the four reviews identified to consolidate the categorisation of decoupling at the macro level (Section 3.1), then it presents the categorisation of decoupling and the definition of AESD at the firm level (Section 3.2). Finally, it introduces the links between ecodesign strategies and decoupling (Section 3.3).

### 3.1. Overview of the four reviews tackling AESD at the macro level

The four reviews that allowed to build the decoupling categorisation at the macro level are summarised in Table 1. They were published between 2019 and 2020, two of them followed a systematic process in the analysis of the articles. Each review has slightly different categorisations of decoupling and some of them, such as Parrique et al. (2019) and Vadén et al. (2020), are much more explicit on the different elements that should be included. The reviews also used different names to characterise AESD.

**Table 1. Comparison of the four reviews identified**

| # | Articles | Review Type | Categorisation of decoupling | Name used to characterise AESD |
|---|---|---|---|---|
| 1 | Parrique et al., (2019) | Not systematic review<br>98 papers analysed | 9 parameters | Absolute sufficient fast enough decoupling for all impacts categories |
| 2 | Hickel and Kallis, (2019) | Not systematic review | 5 parameters | Absolute and at a rate sufficient for returning to and staying within PBs |
| 3 | Vadén et al., (2020) | Systematic review<br>179 papers analysed | 7 parameters | Decoupling needed for ecological sustainability |
| 4 | Haberl et al., (2020);<br>Wiedenhofer et al., (2020) | Systematic review<br>835 papers analysed | 8 parameters | *No specific name* |

### 3.2. AESD at the firm level

The categorisation of decoupling is made of several parameters which represent different conditions that decoupling can have. At the firm level, eight parameters have been identified as playing a role in



https://doi.org/10.1017/pds.2024.153 Published online by Cambridge University Press

categorising decoupling between business growth and environmental pressures. The first parameter is *Environmental indicators*, which characterises the types of indicators representing environmental pressures when decoupling is considered. For example, decoupling can be analysed for one or several impact categories like climate change or biodiversity but also for resource use. The next parameter is *Indicators relationship*, which corresponds to the variation of the environmental and economic indicators over time toward each other. It distinguishes two cases, if the company is growing while the environmental pressures are decreasing, decoupling is considered absolute. On the contrary, decoupling is relative when business growth is faster than the growth of environmental damage or resource use. The third parameter is *Magnitude*, which corresponds to the alignment of decoupling with the environmental absolute thresholds downscaled to the firm level. Additionally, the rate at which the decoupling is happening to meet the environmental absolute thresholds in the given timeframe is also a crucial element. It corresponds to the fourth parameter, *Speed*. For instance, IPCC showed that to limit global warming to 1.5°C, *"it requires global greenhouse gas emissions to peak before 2025 at the latest and be reduced by 43% by 2030"* (Shukla *et al.*, 2022). For some environmental impacts, time is therefore crucial. Additionally, decoupling should continue as long as the company is growing. This is embodied within the parameter *Permanency* corresponding to the durability of the decoupling phenomenon. The sixth parameter is *Economic Scale*, which represents the portion of the value chain of the given firm, which is considered in the boundary of the decoupling analysis. For instance, if a company only decouples its business growth from its greenhouse gas (GHG) emissions coming from their operations (Scope 1 and 2), it is less impactful than decoupling its business growth from GHG emissions coming from both their operations and upstream and downstream emissions (Scope 1, 2 and 3).

**Table 2. Categorisation of decoupling at a firm level**

| # | Parameter | Satisfying degree | Unsatisfying degree |
|---|---|---|---|
| 1 | Environmental indicators | Complete - both resource (material, water, land) and impact indicators (climate change, biodiversity and toxicity) are included | Partial - only some of the indicators are included |
| 2 | Indicators relationship | Absolute - business growth is increasing and resource use/environmental impacts are decreasing | Relative - business growth is increasing, and resource use/environmental impacts are also growing but slower than business growth |
| 3 | Magnitude | Sufficient toward environmental science-based targets | Insufficient toward environmental science-based targets |
| 4 | Speed | Sufficiently rapid rate to meet the environmental science-based targets in the given timeframe | Too slow rate to meet the environmental science-based targets in the given timeframe |
| 5 | Permanency | Permanent - as long as the firm grows, decoupling must happen | Temporary - decoupling is happening only during a limited period of time |
| 6 | Economic Scale | Full-value chain - For instance for GHG emissions (scope 1, 2 and 3) | Parts of the value chain - Single firm or part of the value-chain |
| 7 | Equitable Allocation | Fair | Not-fair |
| 8 | Economic indicators | Physical / Non-monetary indicators | Monetary indicators |

The seventh parameter is *Equitable Allocation* and represents the fairness in the allocation of decoupling efforts. It requires a *"common but differentiated responsibilities"* depending on the types of activities that the firms perform, the geographical location of the firm and its historical responsibilities toward environmental degradation (Rekker *et al.*, 2022). Finally, the last parameter is *Economic indicators*. It describes the type of economic metrics considered to represent business growth in the decoupling analysis. These metrics could be monetary metrics, such as revenue or net profit margin, or metrics relative to the competitiveness of the firms, such as market share. Decoupling can also be measured with non-monetary indicators, for instance by the value delivered by the firm activities, or physical indicators characterising the firm's activities (e.g. tonnes of cement produced). The satisfying degree corresponds to non-monetary or physical metrics. Indeed, monetary metrics can be influenced by many external



https://doi.org/10.1017/pds.2024.153 Published online by Cambridge University Press

elements such as variations in commodity prices, inflation, or shifts in the relative importance of various business activities. This could result in better decoupling rates that do not actually correspond to improved environmental performance (SBTi, 2023b).

For each parameter, two degrees of decoupling are described - a satisfying and an unsatisfying degree (Table 2). The unsatisfying degrees are usually easier to achieve but less pertinent, because they do not make decoupling aligned with AES. On the other hand, the satisfying degrees are more pertinent because they align with AES; however they are also usually more difficult to achieve (Vadén *et al.*, 2020). If all the satisfying degrees are achieved, Absolute Environmental Sustainability Decoupling (AESD) can be claimed. Figure 1 represents a case of AESD at the firm level and the corresponding parameters are described in Table 2.

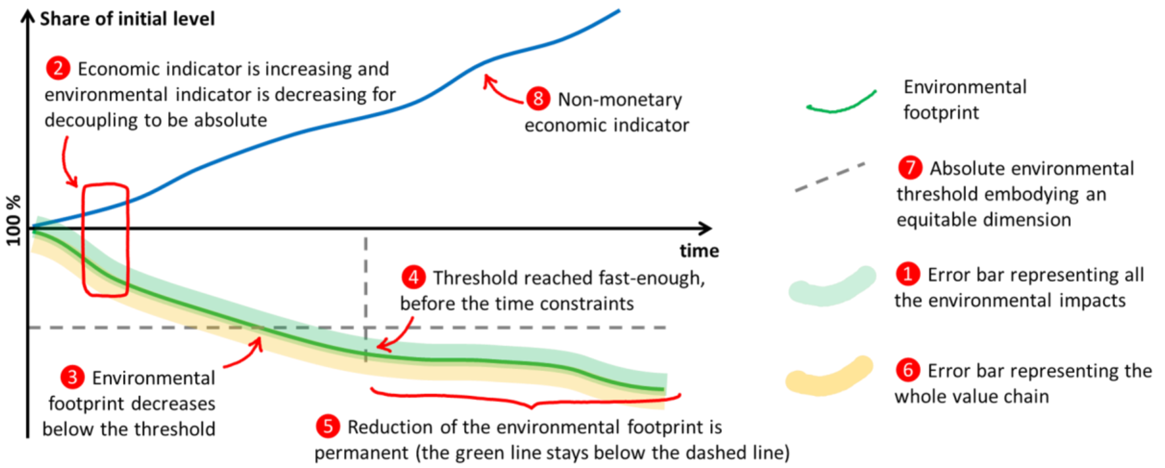


**Figure 1. Graphical representation of AESD at the firm level - representing all the satisfying degrees of the categorisation. Numbers in figure refer to Table 2**

## 3.3. The role of ecodesign to enable AESD in manufacturing firms

To achieve AESD in manufacturing firms, several strategies must be implemented. From redesigning production processes and product design to new business models and consumption patterns, achieving AESD requires crucial transformation (Pigosso and McAloone, 2017). In this section, the potential role of ecodesign strategies is explored by highlighting their influence on AESD. Six ecodesign strategies are taken and analysed through examples to understand their potential role in achieving AESD. Table 3 shows how these strategies could foster AESD, how they are actually not sufficient and how they can even undermine AESD.

All the ecodesign strategies can support AESD to an extent; this mainly because their respective core principles are to reduce certain environmental impacts or resource use. In the meantime, these reductions can lead to reducing costs and increasing profits. This double dynamic directly results in supporting decoupling. However, the analysis points out that often these ecodesign strategies are not enough to achieve AESD and this is due to different elements. First, ecodesign strategies are embedded within a relative approach of sustainability (McDonough and Braungart, 2002) while AESD requires not only to "do better" than previously but to be "good enough" (Hauschild, 2015). Moreover, the ecodesign strategies mainly focus on GHG emissions, the use of energy and materials/resources, but do not include biodiversity for instance, which is also a crucial environmental impact. Sub-optimal focus could lead to so-called "burden-shifting", from one impact category to another. The consumption level is also not directly considered in the ecodesign strategies. For instance, minimising material consumption per product can be insufficient if the overall consumption of the products themselves increases. It was furthermore observed that ecodesign strategies could undermine AESD, even in certain cases. This could occur if the overall environmental impacts were increased, if profit were decreased or when both of them were coupled again. Finally, rebound effects can both induce ecodesign strategies that are not enough or that undermine AESD when they generate impacts that are higher than the initial situation (Guzzo *et al.*, 2023).



https://doi.org/10.1017/pds.2024.153 Published online by Cambridge University Press

**Table 3. Role of ecodesign strategies (ES) in Absolute Environmental Sustainability Decoupling (AESD) [reference: McAloone and Pigosso, (2021) ;Metic and Pigosso, (2022) and discussions]**

| ES | How can ecodesign strategies support AESD? | The ecodesign strategies are not enough | How can ecodesign strategies undermine AESD? |
|---|---|---|---|
| Minimise material consumption | Decreasing raw materials need and solid waste generation can directly decrease resource consumption. It can also increase profit relative to buying less raw materials and spending less for treating solid waste. | In absolute terms, minimising material consumption per product can be insufficient if the overall consumption of the products themselves increases. | Minimising material consumption might lead to more fragile products with shorter lifespans, resulting in more products needed to fulfil the same need. This would directly create a coupling between profit and environmental footprint. |
| Minimise energy consumption | Reducing energy consumption through the different life cycle stages would reduce GHG emissions and increase profit by reducing energy- related costs. | Energy-efficiency improvements could reduce production costs and therefore product prices. In the long term, this could create a higher consumption of the products offsetting the environmental savings made per product and making AESD temporary. | Rebound effects can suppress energy savings, resulting in higher energy consumption and lower profit. Lower energy consumption might even lead to higher disposable income, which in turn could result in increased purchase and utilisation of energy-intensive products. |
| Select low impact resources | Selecting resources or energy sources that are non-toxic, harmless or renewable would result in decreasing the environmental footprint. Additionally, it could cut down some treatment costs during the end-of-life and increase profit. | Using low-impact material (e.g., recycled materials) could make products less robust and more prone to damage leading to higher replacement frequency. This would lead to relative and temporary AESD. | The use of composite recycled plastic for the manufacturing of products could lead in the long term to higher consumption of virgin plastics as composite materials have lower recyclability rate. |
| Optimise product lifetime | Through this eco-design strategy, it can be easier to create offers of products as a service to the users (through remanufacturing, repair, upgrading, etc.) and it can both reduce environmental impacts and increase profits. | Although a product may be designed for a specific lifespan, external factors (e.g. technology development) may prompt users to replace it sooner, resulting in useless product lifetime optimisation that could have increased the product's environmental footprint. | Facilitating the remanufacturing or adaptability of products could lead to the production of new products which increase consumption and foster accumulation instead of substitution. This would lead to higher consumption levels and lower decoupling rates. |
| Extend material lifespan | Facilitating cleaning, composting or combustion in the end-of-life of the products can directly enable material cascades which reduce environmental impacts and can also generate profits. | Selecting recyclable material have positive environmental impacts. However, even if the consumption of products does not change, the number of times when the materials can be recycled is limited directly leading to a shortfall to achieve AESD permanently. | The choice of recyclable material can have worse environmental impacts than non-recyclable material. For instance, if recycling plants are far from the production / use of the products themselves, the environmental footprint from the end-of-life can be higher than the one of the non-recyclable materials through its life cycle. |
| Facilitate disassembly | Facilitating separation operations using reversible joining or recovering parts of the products can lead to reducing costs and increasing profits in end-of-life and decreasing environmental impacts. | The end-of-life relies on consumer behaviours which play a crucial role in how the product is discarded. Even if the product is made for disassembly, it could be discarded as it is and induce environmental impacts. | Facilitating the disassembly of products through customisation (for instance, one part of the product can be changed and customised by its user) could lead to higher consumption levels, more accumulation and lower decoupling rates. |



https://doi.org/10.1017/pds.2024.153 Published online by Cambridge University Press

## 4. Discussion and limitations

### 4.1. Limitations of the parameters of the decoupling categorisation

The categorisation of decoupling, both at the macro and firm level, can contains some limitations due to the choices of category and selection of satisfying and unsatisfying degrees. First, it is important to highlight that the different environmental impacts considered when studying decoupling have different implications regarding to their *Speed*, *Magnitude* and the *g*eographical scope (e.g. local, regional or global - this parameter only exists in the decoupling categorisation at the macro level) considered. Inspecting every environmental impact at the global level is not necessarily desirable. For instance, while GHG emissions are interesting to analyse at a global level, it is not the case for toxicity to ecosystems and humans which is an impact more relevant to analyse at the regional level (Parrique *et al.*, 2019). Similarly, water depletion or clearing of land should be studied at a local level.

The parameters developed in this work to categorise decoupling at the firm level are a theoretical framework, and the AESD definition which results from it is an ideal definition. In practice, verifying and implementing some of these parameters in a firm context can be difficult. For instance, at the firm level, the parameter *Magnitude* can be verified by using the SBTs that firms set for their different impact categories. However, today, SBTs are widely developed only for the impact category of climate change. It would be very difficult to test the *Magnitude* of decoupling between business growth and water or land use at a firm level for instance. Even if frameworks are being developed to downscale other planetary boundaries at the firm level, it is still a work in progress (Science Based Targets Network, 2021). Additionally, the way SBTs for climate change are set today is criticised by several scholars, and they still have many weaknesses (Bjørn *et al.*, 2023). Defining AESD is therefore dependent on the flaws of other frameworks.

Another limitation to highlight is the availability and reliability of the data collected at the firm level. Indeed, environmental accounting has still many approximations and simplifications. For instance, for climate change and GHG of scope 3, it is still very difficult for firms to access data on GHG emissions, and this makes the calculation of GHG footprint long and laborious processes (Ducoulombier, 2021). These limitations could directly influence the parameters *Magnitude* or *Economic Scale* due to unreliable or lack of data. Additionally, firms have started to account for their environmental impacts only recently, and it is difficult to have reliable data for long periods of time. That could make the testing of the parameters *Permanency, Indicators relationship* and *Speed* difficult to interpret. It is also important to highlight that further testing of the decoupling categorisation and AESD definition is necessary to strengthen some of the results, only preliminary interviews were conducted.

Some of the limitations mentioned above hail from the methodological approach chosen. Indeed, downscaling the categorisation from the macroeconomic level to the firm level also contains some limitations. For example, contrary to the firm level, at the macro level data can more easily be standardised, available for a longer timeframe, and be more easily aggregated - all of which makes the verification of the different parameters easier. A conscious delimitation of this study was to treat all manufacturing firms as similar in the translation of the macro to the firm level AESD parameters. A future study could investigate whether this is the case, across all industry sectors.

### 4.2. Operationalisation of AESD through ecodesign strategies and limitations

The categorisation of decoupling and definition of AESD can be used as a strategic tool to foster companies' sustainability transition. Exploring the role of ecodesign strategies to implement AESD sheds light to their potential and limitations. In particular, ecodesign strategies have shortfalls regarding the variety of *Environmental Indicators* and their inherent focus on relative decoupling (i.e., focus on reducing the environmental impacts per product and are not looking into the overall consumption of these products). Consumption is a key factor that directly influences AESD, even if the impacts per product decrease, the overall environmental footprint increases if more products are consumed. This is directly impacting the parameter *Indicators Relationship*. Furthermore, the rebound effects examples reveal that the impacts of the ecodesign strategy might be temporary, directly limiting the *Permanency* of AESD. Finally, it is important to highlight that the ecodesign strategies do not directly tackle the parameters *Speed* and *Magnitude* as they require quantitative elements to be tested, nor the parameter *Equitable Allocation*. Even if environmental issues are incorporated at the product/product-service level with a life cycle perspective, the leverage for AESD is limited. As a result, it is evident that ecodesign strategies alone are insufficient to fully support AESD goals.

The use of the parameters allows to highlight some shortfalls of the ecodesign strategies as mean to achieve AESD. The AESD parameters could be used by designers to integrate considerations to tackle the potential shortfall earlier in the process. For instance, for a given ecodesign strategy quantifying environmental impacts for multiple impact categories *(*parameter *Environmental Indicators)* or considering consumption increases in advance *(*parameter *Indicators Relationship)* could help designing products that could enable AESD at the firm level.

However, this is only a preliminary study and further research is imperative to understand how ecodesign strategies can be adapted to align more closely with the objectives of AESD. It could be interesting to know to what extent deploying multiple ecodesign strategies together could contribute to the AESD targets on a firm level. For instance, design for material reuse, design for disassembly and materials substitution alone have only limited contribution to reach AESD but their combined application could bring the company closer to AESD targets. To enhance the applicability and likelihood of AESD in practice, it is necessary to interpret it to more operational levels within the firm, such as business units or product portfolios, as important business and design decisions are made at these levels, directly affecting the leverage of the firm to decouple. In addition, this paper only focused on looking at the strategies independently and on a single design area: ecodesign. It could be interesting to analyse multiple ecodesign strategies together and to have a broader exploration of how design science could contribute to AESD - especially looking into the roles of product-service-systems, design organisation and management through business models (Pigosso and McAloone, 2017), or ecodesign management practices (Pigosso *et al.*, 2014).

## 5. Conclusion

AES is key to enable humanity to carry its activities within the biophysical limits of the planet. To achieve that, AES needs to be incorporated in the sustainable transition pathway of firms. The aim of AESD is to enable companies to continue growing, whilst also reducing their footprint and contributing to staying within the environmental budgets of the Earth system (without offsetting).

However, there is hitherto only a focus on decoupling at a macro level, and decoupling at a firm level within a framework of AES is not yet applied. By translating the decoupling categorisation from a macro to a firm level, this paper highlighted eight criteria that are required at a firm level to achieve AESD. Decoupling needs to happen between business indicators - that are not only monetary - and all the environmental impacts and resource use across the entire value chain. Decoupling must be absolute, permanent, fast enough and sufficient towards science-based mitigation targets. Moreover, decoupling effort should be allocated according to fair sharing principles, according to the types of needs fulfilled by companies and their historical responsibilities. If all these conditions are respected, firms decoupling trajectories are aligned with AES and their sustainable transition is good enough to respect absolute environmental thresholds. This paper contributes to the state-of-the-art by proposing an initial methodology to translate decoupling mechanisms to the firm level, at the same time as exploring the role and limitations of ecodesign strategies in supporting companies in achieving AESD.

Nevertheless, multiple steps are still required for manufacturing firms to implement AESD and future research should focus on those. First, it is important to understand how to quantify the current and expected level of AESD at the firm level. Indeed, the decoupling categorisation paves the way to develop decoupling indicators aligned with AESD but it only brings a qualitative categorisation that is difficult to operationalise for firms. Then, as demonstrated at the macroeconomic level, there is currently no evidence of AESD happening at the global or country scale (Haberl et al., 2020). This brings direct concerns regarding the feasibility of AESD at the firm level, and these concerns should be explored. This especially raises questions regarding the business growth targets of manufacturing firms and the societal needs they are fulfilling. Finally, the preliminary exploration of ecodesign role in achieving AESD raises more questions regarding the role of design science in achieving AES in manufacturing firms.



https://doi.org/10.1017/pds.2024.153 Published online by Cambridge University Press

## Acknowledgment

This research was supported by the Centre for Absolute Sustainability, from the Technical University of Denmark (DTU). The authors acknowledge the funding support from DTU to conduct this research.

## References

Aurich, J.C., Werrel, M. and Glatt, M. (2022), "Design Guidelines towards Absolute Sustainability for technical Product-Service Systems", 11th International Conference on Through-Life Engineering Services - TESConf2022, pp. 1–9, https://doi.org/10.57996/cran.ceres/1.

Bjørn, A., Matthews, H.D., Hadziosmanovic, M., Desmoitier, N.L.R., Addas, A. and Lloyd, S.M. (2023), "Increased transparency is needed for corporate science-based targets to be effective", Nature Climate Change, Vol. in print, https://dx.doi.org/10.1038/s41558-023-01727-z.

Bjørn, A., Tilsted, J.P., Addas, A. and Lloyd, S.M. (2022), "Can Science-Based Targets Make the Private Sector Paris-Aligned? A Review of the Emerging Evidence", Current Climate Change Reports, Springer Science and Business Media Deutschland GmbH, 1 June, https://dx.doi.org/10.1007/s40641-022-00182-w.

Ducoulombier, F.Y. (2021), "Understanding the Importance of Scope 3 Emissions and the Implications of Data Limitations", The Journal of Impact and ESG Investing, Vol. 1 No. 4.

Guzzo, D., Walrave, B. and Pigosso, D.C.A. (2023), "Unveiling the dynamic complexity of rebound effects in sustainability transitions: Towards a system's perspective", Journal of Cleaner Production, Elsevier, Vol. 405, p. 137003, https://dx.doi.org/10.1016/J.JCLEPRO.2023.137003.

Haberl, H., Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Brockway, P., Fishman, T., et al. (2020), "A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part II: Synthesizing the insights", Environmental Research Letters, Institute of Physics Publishing, Vol. 15 No. 6, https://dx.doi.org/10.1088/1748-9326/AB842A.

Hauschild, M.Z. (2015), "Better - but is it good enough? On the need to consider both eco-efficiency and eco-effectiveness to gauge industrial sustainability", Procedia CIRP, Vol. 29, Elsevier, pp. 1–7, https://dx.doi.org/10.1016/j.procir.2015.02.126.

Hickel, J. and Kallis, G. (2020), "Is Green Growth Possible?", New Political Economy, Vol. 25 No. 4, pp. 469–486, https://dx.doi.org/10.1080/13563467.2019.1598964.

Johansson, G. (2002), "Success factors for integration of ecodesign in product development A review of state of the art", Environmental Management and Health, # MCB UP Limited, Vol. 13 No. 1, pp. 956–6163, https://dx.doi.org/10.1108/09566160210417868.

McAloone, T.C. and Pigosso, D.C.A. (2020), "Ecodesign: Developing products with enhanced environmental performance", in Bender, B. and Gericke, K. (Eds.), Pahl/Beitz Konstruktionslehre - Methoden Und Anwendung Erfolgreicher Produktentwicklung, Springer Vieweg Berlin, Heidelberg, pp. 1–33, https://dx.doi.org/10.1007/978-3-662-57303-7.

McDonough, W. and Braungart, M. (2002), Cradle to Cradle: Remaking the Way We Make Things, North Point Press: New York, North Point Press.

Metic, J. and Pigosso, D.C.A. (2022), "Research avenues for uncovering the rebound effects of the circular economy: A systematic literature review", Journal of Cleaner Production, Elsevier, 25 September, https://dx.doi.org/10.1016/j.jclepro.2022.133133.

Moshrefi, S., Abdoli, S., Kara, S. and Hauschild, M. (2020), "Product portfolio analysis towards operationalising science-based targets", Procedia CIRP, Elsevier B.V., Vol. 90 No. March, pp. 377–382, https://dx.doi.org/10.1016/j.procir.2020.02.127.

OECD. (2002), Indicators to Measure Decoupling of Environmental Pressure from Economic Growth.

Otero, I., Farrell, K.N., Pueyo, S., Kallis, G., Kehoe, L., Haberl, H., Plutzar, C., et al. (2020), "Biodiversity policy beyond economic growth", Conservation Letters, Vol. 13 No. 4, p. 33, https://dx.doi.org/10.1111/conl.12713.

Parrique, T., Barth, J., Briens, F., Kerschner, C., Kraus-Polk, A., Kuokkanen, A. and Spangenberg, J.H. (2019), "Decoupling debunked: Evidence and arguments against green growth as a sole strategy for sustainability", European Environmental Bureau, p. 80.

Pigosso, D. and McAloone, T. (2017), "How can design science contribute to a circular economy?", Proceedings of the International Conference on Engineering Design, ICED, Vol. 5: Design, Vancouver, Canada, pp. 299–307.

Pigosso, D.C. a, Mcaloone, T.C. and Rozenfeld, H. (2014), "Systematization of best practices for ecodesign implementation", Proceedings of the 13th International Design Conference DESIGN 2014, Design Society, pp. 1651–1662.

Plouffe, S., Lanoie, P., Berneman, C. and Vernier, M.F. (2011), "Economic benefits tied to ecodesign", Journal of Cleaner Production, Vol. 19 No. 6–7, pp. 573–579, https://dx.doi.org/10.1016/j.jclepro.2010.12.003.

Rekker, S., Ives, M.C., Wade, B., Webb, L. and Greig, C. (2022), “Measuring corporate Paris Compliance using a strict science-based approach”, Nature Communications, Nature Research, Vol. 13 No. 1, https://dx.doi.org/10.1038/S41467-022-31143-4.
Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S.E., Donges, J.F., Drüke, M., et al. (2023), “Earth beyond six of nine planetary boundaries”, Science Advances, NLM (Medline), Vol. 9 No. 37, p. eadh2458, https://dx.doi.org/10.1126/SCIADV.ADH2458.
Ryberg, M.W., Owsianiak, M., Clavreul, J., Mueller, C., Sim, S., King, H. and Hauschild, M.Z. (2018), “How to bring absolute sustainability into decision-making: An industry case study using a Planetary Boundary-based methodology”, https://dx.doi.org/10.1016/j.scitotenv.2018.04.075.
SBTi. (2023a), Monitoring Report 2022.
SBTi. (2023b), SBTi Corporate Manual, Science Based Targets.
Science Based Targets Network. (2021), SBTs for Nature Initial Guidance for Business Technical Annexes.
Shukla, P.R., Skea, J., Slade, R., Al Khourdajie, A., van Diemen, R., McCollum, D., Pathak, M., et al. (2022), Climate Change 2022 - Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, https://dx.doi.org/10.1017/9781009157926.
Vadén, T., Lähde, V., Majava, A., Järvensivu, P., Toivanen, T., Hakala, E. and Eronen, J.T. (2020), “Decoupling for ecological sustainability: A categorisation and review of research literature”, Environmental Science and Policy, Elsevier Ltd, 1 October, https://dx.doi.org/10.1016/j.envsci.2020.06.016.
Vezzoli, C. and Manzini, E. (2008), Design for Environmental Sustainability, https://dx.doi.org/10.1007/978-1-84800-163-3 British.
Wegge Hjalsted, A., Laurent, A., Andersen, M.M., Olsen, K.H., Ryberg, M. and Hauschild, M. (2020), “Sharing the safe operating space Exploring ethical allocation principles to operationalize the planetary boundaries and assess absolute sustainability at individual and industrial sector levels”, https://dx.doi.org/10.1111/jiec.13050.
Wiedenhofer, D., Virág, D., Kalt, G., Plank, B., Streeck, J., Pichler, M., Mayer, A., et al. (2020), “A systematic review of the evidence on decoupling of GDP, resource use and GHG emissions, part I: Bibliometric and conceptual mapping”, Environmental Research Letters, Institute of Physics Publishing, 1 June, https://dx.doi.org/10.1088/1748-9326/ab8429.

## Appendix A

The search string used in Scopus is as followed:
"( TITLE-ABS-KEY ( decoupl* OR product* OR intensit* ) AND TITLE-ABS-KEY ( emission* OR resource OR "environmental impact" ) AND TITLE-ABS-KEY ( gdp OR "economic growth" ) AND TITLE-ABS-KEY ( sustainability OR "absolute decoupling" OR "green growth" OR "degrowth" OR ecolog* ) ) AND ( LIMIT-TO ( DOCTYPE , "re" ) )".

## Appendix B

The table of Appendix B can be found at this doi address https://dx.doi.org/10.11583/DTU.24553276