SCALABILITY AND POTENTIAL OF EMERGING CLEAN TECHNOLOGIES: A TAXONOMY-BASED APPROACH

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Overview

Emerging technologies for decarbonization will play a fundamental role in addressing global greenhouse gas emissions and facilitating the transition to a low-carbon economy (IEA, 2023). However, many of these technologies face significant uncertainties during their development and deployment stages. The lack of reliable assessments and high investment risks contribute to the "Valley of Death", where early-stage technologies fail to secure funding to advance beyond laboratory settings (Auerswald & Branscomb, 2003).

This research has a dual purpose:

1. To identify the factors impacting the scalability and potential of emerging technologies for decarbonization.
2. To determine how the importance of these factors changes depending on the stage of development (Development or Deployment) and the technological sector.

To address these research questions, the study established a taxonomy that categorizes the factors influencing the scalability and potential of emerging technologies for decarbonization. This taxonomy organizes factors into structured categories to standardize their evaluation across different sectors and stages of development. By aligning these factors with specific stages (Development or Deployment) and sectors, the taxonomy enables a nuanced analysis of their role in overcoming scalability barriers and enhancing technological potential. This approach provides insights to support informed decision-making by stakeholders, such as venture capitalists, in prioritizing technologies with the highest potential impact on decarbonization.

Methods

The study followed two main steps:

1. **Factor Identification and Database Creation**:
   - A systematic review of scientific literature on models for assessing emerging technologies was conducted. While this review covered a broad range of assessment frameworks, weights assigned to factors were collected in a database when authors explicitly provided them, such as in Multi-Criteria Decision-Making (MCDM) models. In these cases, the reported weights were extracted and incorporated into the analysis.
   - From these models, the factors considered were extracted along with their weights. Additional data such as the development stage (Development or Deployment), type of analysis (e.g., Economic, Sustainability, Scalability), and technological sector (e.g., Power Storage, Carbon Capture) were also recorded.
   - Using this data, the extracted factors were aligned with a taxonomy presented in this study to ensure consistent classification. This taxonomy served as the foundation for subsequent analysis.
2. **Statistical Analysis of Factor Weights**:
   - The taxonomy enabled a unified approach to analyze the variability in factor weights. An ANOVA analysis was performed to evaluate the impact of the development stage (Development or Deployment) on the assigned weights.
   - Additionally, a similarity analysis was conducted using Euclidean distance to evaluate the closeness between models. This approach aimed to better understand sector-specific dynamics by identifying shared characteristics among models analyzing technologies within the same sector.

Results

Taxonomy

A taxonomy of factors relevant to evaluating the scalability and potential of emerging technologies for decarbonization is presented. This taxonomy organizes the factors into five key Categories and fifteen Factors:

1. **Economic** → CAPEX – OPEX – Market Risk/Potential
2. **Technical** → Technology details – Performances
3. **Environmental** → GHG emissions – Environmental impact – Resource consumption
4. **Technological** → Complexity – Maturity – Manufacturability – System integration

5. **External factors** → Supply chain risk – Policy and Regulation – Safety and Social impact

The findings from the literature review revealed that while significant progress has been made in methodologies for Techno-Economic (TEA) and Life-Cycle (LCA) assessments of early-stage technologies (Zimmermann et al., 2022), a critical gap exists in integrating **Technological** factors into assessments (Sievert et al., 2024). Addressing this gap requires the development of frameworks that systematically incorporate technological factors into early-stage assessments, ensuring a more comprehensive and reliable evaluation of emerging technologies.

Statistical Analysis

ANOVA Analysis

The ANOVA analysis revealed that the development stage (Development or Deployment) significantly impacts the weights assigned to all Categories of factors (p-value < 0.05). Specifically:

- **Economic** (Category 1) and **Technological** (Category 4) factors are more relevant for technologies in the **Development** stage. This highlights the need for Venture Capitalists (VCs) to prioritize aspects like complexity and manufacturability during this phase, as uncertainty around technological feasibility remains high.
- **External Factors** (Category 5) gain importance in the **Deployment** stage. This shift reflects the increasing relevance of regulatory, social, and external considerations as technologies move closer to commercialization.

These findings suggest that VCs should focus on assessing technological challenges in early stages, while external factors like regulation and social acceptance become critical in later stages of deployment.

Similarity Analysis

The Euclidean distance analysis demonstrated that models designed to evaluate technologies within the same sector are more similar to each other. This finding highlights the relevance of the technological sector in determining the impact of specific factors on scalability and potential. It suggests that sector-specific dynamics play a critical role in shaping the importance of factors, complementing the influence of the development stage. By accounting for both sector and stage, the framework provides a nuanced understanding of the challenges and opportunities associated with scaling emerging technologies.

Conclusions

This study presents a taxonomy of factors relevant to evaluating the scalability and potential of emerging technologies for decarbonization. Organized into five categories (Economic, Technical, Environmental, Technological, and External Factors), this taxonomy provides a structured foundation for assessing key dimensions influencing technological advancement.

The statistical analyses conducted revealed critical insights. The development stage (Development or Deployment) significantly influences the relevance of factors. Economic and Technological aspects are particularly crucial in early stages, where technological complexity and manufacturability must be addressed to mitigate uncertainties. Conversely, External factors become more prominent in later stages, reflecting the increasing importance of regulatory, social, and external considerations as technologies near commercialization. Sector-specific dynamics also play a critical role, with models evaluating technologies within the same sector showing greater similarity. These findings emphasize the need for strategies tailored to both the stage and sector of development to address scalability challenges effectively.

These findings provide actionable insights for stakeholders, particularly Venture Capitalists, to optimize investment decisions by focusing on stage-specific and sector-specific priorities.

References

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