Journal of Cleaner Production 243 (2020) 118603

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Maturity-based analysis of emerging technologies in the Brazilian Power Sector

Marlon Max H. Bellido, PhD [a], Hudson Lima Mendonça, M.Sc. [b], Marcus Vinicius de Araújo Fonseca, PhD [b], David Alves Castelo Branco, PhD [a], Amaro Olimpio Pereira Jr., PhD [a, *]

[a] Energy Planning Program — PPE/COPPE/UFRJ, Avenida Horácio de Macedo, 2030, Centro de Tecnologia, Bloco C-211, Cidade Ilha do Fundão, Rio de Janeiro, Brazil

[b] Technological Innovation Laboratory — Labrintos/COPPE/UFRJ, Avenida Horácio de Macedo, 2030, Centro de Tecnologia, Bloco G-207, Cidade Ilha do Fundão, Rio de Janeiro, Brazil

ARTICLE INFO

Article history:
Received 14 June 2019
Received in revised form
12 September 2019
Accepted 25 September 2019
Available online 26 September 2019

Handling editor: Giorgio Besagni

Keywords:
Startups
CleanTech
Hype cycle curve
Microgrids
Photovoltaic panels
Energy storage

ABSTRACT

This study proposes a methodology for quantifying the development level of new technologies introduced into the Brazilian Power Sector. The objective is to provide information reflecting technological trends, thus creating opportunities to invest in startups. Based on the findings of a survey conducted with CleanTech startups in Brazil, this analysis is based on Hype Cycle curves for the three main technologies: energy storage, photovoltaic panels and microgrids. The assessment shows that photovoltaic panels and microgrid technologies are more mature than energy storage. However, expectations for technologies available on the market are decreasing, due mainly to a lack of incentives for their use.

1. Introduction

The power sector is currently subject to abroad range of pressures for change, imposed not only by social and environmental factors, but also technological aspects that reflect shifts in paradigms that prevailed for years. Known as an energy transition, this process spurs the expansion of generation using cleaner sources, with substantial impacts on energy sales methods.

Similar to what happened in the communication sector during the Internet revolution, CleanTechs have the potential to play a transforming role in the context of an energy transition moving towards a low-carbon economy as they underpin the appearance of new business models, while also developing new technologies.

The term CleanTech can be applied to a technology or business model providing a wide range of processes, products and services using renewable energy and materials, with fewer natural resources, in parallel to less pollution and lower waste production (Kachan and Fugere, 2013). Cleaner technologies are acknowledged as an important economic growth multiplier in the XXI century (Montalvo and Kemp, 2008).

CleanTechs are usually developed by small high-tech firms with significant growth potential, often focused on innovative projects. This profile is common among startups, with CleanTech startups often defined as businesses engaged in activities involving risks deriving from rapid changes in business environments that demand new technological solutions.

The survival of these companies depends on constant technological trend analysis based on familiarity with new but mature technologies, among other aspects, allowing them to implement their strategic business plans and create a stream of activities that spotlights their actions on the market. These companies need the Research and Development (R&D) support, which often comes

* Corresponding author.
E-mail addresses: marlonmax@ppe.ufrj.br (M.M.H. Bellido), hudson@labrintos.coppe.ufrj.br (H.L. Mendonça), vfonseca@labrinto.coppe.ufrj.br (M.V.A. Fonseca), davidbranco@ppe.ufrj.br (D.A.C. Branco), amaro@ppe.ufrj.br (A.O. Pereira).

https://doi.org/10.1016/j.jclepro.2019.118603
0959-6526/

from the government. Venture capital investors could be an alternative source of backing, as they usually finance startups in their initial stages, despite high risk levels (Gaddy et al., 2017).

As venture capital risk profiles change from investor to investor, a platform is needed where Cleantech Startups can showcase the maturity of their technologies in order to maintain a keen competitive edge on the market. This platform could also match startups to the risk profiles of venture capital investors.

Today's constantly-changing business environment is ratcheting up uncertainties, particularly through the adoption of new technological solutions in the power sector. Technological trend analyses are consequently essential for business success, as in-depth familiarity with technology life-cycles endows companies with competitive advantages that broaden their market penetration and steer the effective implementation of their strategic business plans.

This issue has not slipped by unnoticed in Brazil, particularly in view of its leading role in the renewable energy field and focus on sustainable development. However, the CleanTech startups ecosystem is still fairly incipient, despite massive growth potential. The main hurdle is the lack of investment for placing new technologies on the market (Mendonça, 2017).

Particularly noteworthy among CleanTechs that should affect the Brazilian power sector to a significant extent are smart grids, photovoltaic panels, energy storage, energy efficiency and electric vehicles. Although many of these technologies are being developed by startups, an integrated overview of these initiatives and their mapping is a complex task that has not yet been undertaken in Brazil.

The intention of this study is thus to use a methodology to assess the development levels of some technologies in Brazil, based on a survey of Cleantech startups. This is an analytical approach for defining possible technologies developed and/or applied by startups that have the potential to spur changes in the Brazilian power sector.

The rest of this paper is structured as follows: Section 2 presents the Hype Cycle; Section 3 outlines the materials and methodology developed to build the Hype Cycle, based on studies found in the literature; Section 4 examines and discusses the results; And Section 5 lists the conclusions and limitations, with suggestions for further research.

2. The Hype Cycle curve

Business decisions often depend on a good understanding of the maturity and evolution of technologies; however, predicting the development of technologies and/or products that are still at the start of their life-cycles is a difficult task.

There are many uncertainties associated with technological development, which can significantly jeopardize or hamper the market penetration of new technologies (Dedehayir and Steinert, 2016). Investors have consequently been using metrics to measure the maturity and readiness of systems and technologies. However, it is not often clear whether the aim of these metrics and methods is to measure maturity or readiness. Overall, the literature does not distinguish between these two terms and rarely specifies whether a method was developed for a specific system or technology. Moreover, in most cases, the applicability of tools and methods related to technology remains vague (Azizian et al., 2009).

Azizian et al. (2009) carried out an extensive evaluation of these methods. The Technology Readiness Level (TRL) method was the first to be developed for this purpose; however, it was not considered an adequate metric because it is a static methodology, with many other qualitative, quantitative and automatic methods suggested as replacements.

One of these most prominent methods is the Hype Cycle, which can provide valuable information on creative analysis (as illustrated) for policy makers and managers.

Introduced in 1995 by Gartner Consulting, Hype Cycle Methodology enhances technology development analyses and predictions. The model shows the technology pathway throughout its lifetime (dynamic methodology) in terms of expectations and visibility of its value. It depicts the typical progress of the emerging technology, from over-enthusiasm to disappointment. This methodology provides models that help companies to pinpoint the perfect time to adopt a new technology, rather than merely providing performance indicators that measure the gaps between hype and reality (Linden and Fenn, 2003).

The Hype Cycle balloons with every innovation that some somehow captures society's imagination: a management trend, a new business process or a new technology, burgeoning when an innovation is launched and gradually maturing over time.

Although limited largely to academia so far, there is growing interest in technology and innovation management literature, particularly for technological predictions (Dedehayir and Steinert, 2016).

Expectations soar when people are excited about innovation, but their hopes are easily dashed, as these new technologies rarely fulfill their promises. Technology develops at a different pace, often lagging behind expectations. Two different curves can describe these paired factors: a bell-shaped curve representing the initial enthusiasm and disappointments caused by positive and negative reactions; and an S-shaped curve representing the innovation performance, which can gradually and continuously improve, finally producing less motivated responses (Fenn and Raskinno, 2008).

The Hype Cycle merges two different equations/curves. Focused on human behavior, the first part of the curve or equation describes expectations through the shape of a Hype-level bell curve. The second part, the equation is a classic sigmoid curve that describes technological maturity (Dedehayir and Steinert, 2016).

The Hype Cycle is also a measurement of knowledge and risk. Companies know little about the technology under analysis at the beginning of the cycle, making it hard to assess costs and benefits, so the risk is high at this stage. It is easier to know where and when to apply the technology at the end of the cycle, when the company is already familiar with it, as this knowledge reduces the associated risks (Linden and Fenn, 2003).

The Hype Cycle curve may be divided into five phases (Gartner, 2018):

Technology Trigger: Phase when the new technology (usually still a prototype) receives too much publicity and attracts the attention of a specific sector. Flying autonomous vehicles, artificial general intelligence and Blockchain for data security are examples of technologies at this maturity level.

Peak of Inflated Expectations: As expectations inflate, more suppliers offer the technology, often new companies and small-scale vendors who piggyback on the great publicity for the technology to their own benefit. Some companies outside the new technologies sector explore how it might be used in their business strategies. Digital twin, biochips and autonomous mobile robots are examples of technologies at this maturity level.

Sliding into the Trough of Disillusionment: The image of the technology becomes associated with mistakes and failures to keep pace with inflated corporate expectations, as the media headlines flaws noted during initial tests, thus discrediting the technology. Mixed reality, smart fabrics and augmented reality are examples of technologies at this maturity level.

Slope of Enlightenment: More companies using the technology provide greater real-life experience, leading to a better understanding of its applicability, risks and benefits. Vendors seek ways to finance marketing and sales as they jostle for better positions, while second and third generation products are launched, and methodologies and tools streamline development processes. Social marketing management platforms is an example of technology at this maturity level.

Plateau of Productivity: This is the threshold of mainstream adoption of the technology, as its real benefits become more widespread and generally accepted, seamlessly embodied in out-of-the-box solutions that encompass a steady stream of additional service elements, as the technology matures. Data management platforms is an example of technology at this maturity level.

3. Materials and methods

A set of publications that address the Hype Cycle construction methods was assessed in order to generate these curves, starting out by quantifying the number of papers published in journals, as well as patents, books and articles in specialized journals, as shown in Table 1.

As previously highlighted, the Hype Cycle can be developed through two different curves: a bell curve (from the Technology Trigger through to the Trough of Disillusionment) and a sigmoid curve from the Slope of Enlightenment to the Plateau of Productivity).

It is thus worth pointing out that the analyzed papers follow the procedure of counting the number of items linked to the technology in order to measure aspects of related expectations, which is the first stage of the Hype Cycle. These items may be found in books, newspapers or scientific journals, and can be gathered together through bibliometric reviews. In contrast, patent statistics are used for the second stage and may also be gathered through bibliometric review.

Some papers (Jun, 2012a; Sasaki, 2015; Steinert and Leifer, 2010) assess Hype Cycle development through the conjunction of two curves, indicating that the former addresses the enthusiasm and disappointment with the technology (bell curve), while the latter portrays innovation performance (sigmoid curve).

Other papers (Adamuthe et al., 2015; Budde et al., 2015; Jarvenpaa and Makinen, 2008a; Jarvenpaa and Makinen, 2008b; Jun, 2012b; Lente et al., 2013; Steinert and Leifer, 2010) empirically develop the generation of the Hype Cycle based on data gathered through Google searches. In some cases, comparisons are then drawn between the shapes of the Hype Cycle developed by Gartner, as described in several papers on this method (Adamuthe et al., 2015; Steinert and Leifer, 2010).

However, although these papers show several ways of building a curve, according to Steinert and Leifer (2010), one of the weaknesses of the Hype Cycle is the lack of a mathematical model allowing quantitative reproduction of the respective analyses by anyone, not only Gartner. Furthermore, Steinert and Leifer (2010) also pinpoint the lack of theoretical support, or a methodological procedure, as one of the reasons why the Hype Cycle model is not easily accepted by the scientific community. It is thus necessary to develop a mathematical model that properly defines the curve.

In other words, the model is not mathematically defined. This means that the proposition of combining the bell curve (reflecting expectations of the technology) with the sigmoid curve (indicating technological performance), is adversely affected by the absence of a mathematical relation able to describe this phenomenon (Steinert and Leifer, 2010).

This issue was addressed by Sasaki (2015), who combined sigmoid (S-shaped) curves with the subsequent curve adjustment based on polynomials. In order to find the Hype Cycle, Sasaki (2015) suggested a combination of the sigmoid and bell curves. He assessed the Logistic and Gompertz functions in order to reach his goal, defining the Gompertz function as the most appropriate for the proposed combination.

Finally, the curves were adjusted (based on polynomials) at 5°, 7°, and 9°, with the latter (9° polynomial) presenting the best adjustment. This author carried out a case study and applied the methodology to three technologies in Japan: customer relationship management (CRM), Supply Chain Management (SCM) and cloud computing. The Nikkei newspaper (the main economic newspaper in Japan) was the selected database, searched for articles published between 1990 and March 2014; in all, 4772 articles and papers were analyzed.

3.1. Bibliometric survey

The assessed technologies were selected through a survey aimed at mapping CleanTech startups in Brazil at all maturity levels, from initial concept/idea through to fully operational and even in expansion. Conducted from August to September 2018, this survey of 136 startups provided an overview of the CleanTech startup ecosystem in Brazil. This contributes to the development of public policies and instruments that benefit these companies, building up stronger links with major energy utilities in order to scale up their innovations.[1]

Among these mapped startups, 56 were in the CleanTech segment[2]; 35 were in the energy subsegment; 22 in wind energy; 10 in hydro; and five focused on fuel cells. There were also nine startups in the energy storage segment; five in the electricity storage subsegment; three focused on chemicals storage; and two specializing in mechanical and heat storage, respectively.

Three technologies were chosen from this survey, due to their impacts on the Brazilian Power Sector: energy storage, photovoltaic panels and microgrids. It is worth noting that these technologies have been used in Brazil for decades for servicing remote communities, which is why they were selected for analysis in this paper.

In order to construct the Hype Cycle curve, a search was conducted in the Web of Science (WoS) database, using the following steps, as shown in Fig. 1.

Step 1 of a preliminary search that defined the keywords. Their selection is an important step that can influence the outcomes of the survey. Search terms were selected for three technologies: energy storage; photovoltaic panels; and microgrids.

The first step focused on exploring the dynamic progression of scientific output on technology through to 2018. The Web of Science database was chosen due to its scope and use in other bibliometric studies, since it offers access to the references and abstracts of many papers in several fields of knowledge. The WoS database includes some 12,000 journals, with the possibility of consulting five collections: the Science Citation Index Expanded (SCI-EXPANDED); the Social Sciences Citation Index (SSCI); the Arts & Humanities Citation Index (A&HCI); the Conference Proceedings Citation Index - Science (CPCI-S); and the Conference Proceedings Citation Index - Social Science & Humanities (CPCI-SSH). This database offers tools for analyzing references, citations and indexes.[3]

Consideration was also given to the possibility of conducting a survey of reports written by the industry and/or the government. However, these reports are not published frequently enough in

[1] See http://mediadrawer.gvces.com.br/publicacoes-2/original/ecossistema-de-startups-de-cleantech-no-brasil.pdf.

[2] In the survey, each respondent was able to select one or more business segments of their company.

[3] Author-level metric, which attempts to measure both the productivity and citation impact of a scientist or all academic publications.

Table 1
Summary of papers on Hype Cycle and/or systematic literature review.

Title	Subject	Method	Reference
Drivers, barriers and enablers to end-of-life management of solar photovoltaic and battery energy storage systems: A systematic literature review	End-of-life management of solar photovoltaic and battery energy storage systems	Methodological and geographical distribution of published papers on end-of-life management of solar energy systems. Research concentrated within Europe, some parts of Asia, and North America	Salim et al. (2019)
Analysis of the energy storage technology using Hype Cycle approach	Evaluation and technology prediction of some energy storage technologies	Number of news items and patents in Google Trends and Google Patent	Khodayari and Aslani (2018)
Simulating hype cycle curves with mathematical functions: Some examples of high-tech trends in Japan	Customer relationship management (CRM), supply chain management (SCM) and cloud computing	Number of news articles x year. Mathematical formulation and polynomial matches	Sasaki (2015)
An empirical analysis of hype cycle: A case study of cloud computing technologies	Cloud computing technologies	Number of news articles, patents and papers x year	Adamuthe et al. (2015)
On the relation between communication and innovation activities: A comparison of hybrid electric and fuel cell vehicles	Hybrid-electric vehicle (HEV) and Fuel-cell vehicle (FCV) technology	Relation between R&D activities and communication activities in the automobile industry using patent statistics, press releases and interviews	Budde et al. (2015)
The expert systems life cycle in AIS research: What does it mean for future AIS research?	Life cycle of accounting-related expert system publications	Distribution of expert system research x year	Gray et al. (2014)
Comparing technological hype cycles: Towards a theory	Studying and comparing results of case studies on three hypes in three different empirical domains of Voice over Internet Protocol (VoIP) technology, gene therapy and high-temperature superconductivity	Number of news articles x year	Lente et al. (2013)
Classification and trend analysis of UML books (1997–2009)	Unified Modeling Language (UML)	Statistical survey of the number of books published on UML	Garousi (2012)
A comparative study of hype cycles among actors within the socio-technical system: With a focus on the case study of hybrid cars	Hybrid cars	Search traffic on Google, news articles and patent statistics in order to develop hype cycle curves for users, producers or researchers	Jun (2012a)
Strategic responses to fuel cell hype and disappointment	Stationary fuel cells	News articles x year	Konrad et al. (2012)
Technology trends analysis and forecasting application based on decision trees and statistical feature analysis	500 emerging technologies	Papers and patents information. Decision tree model	Kim et al. (2012)
An empirical study of users' hype cycle based on search traffic: The case study on hybrid cars	Hybrid cars	Measuring user hype cycles through search traffic analysis	Jun (2012b)
What happens after a Hype? How changing expectations affected innovation activities in the case of stationary fuel cells	Empirical study of hype and disappointment of stationary fuel cells limited to scope of German speaking Europe	Number of news articles x year	Ruef and Markard (2010)
Scrutinizing Gartner's Hype Cycle approach	46 emerging technologies	Scrutinize the validity of Gartner's hype cycle approach through in-depth theoretical discussion and empirical analysis	Steinert and Leifer (2010)
An empirical study of the existence of the hype cycle: A case of DVD technology	DVD technology	Technology life-cycle indicators and news media with bibliometric measures	Jarvenpaa and Makinen (2008a)
Empirically detecting the hype cycle with the life cycle indicators: An exploratory analysis of three technologies	MP3, Bluetooth and Blu-ray technologies	Bibliometrics	Jarvenpaa and Makinen (2008b)
The social dynamics of expectations: The interaction of collective and actor-specific expectations on electronic commerce and interactive television	Electronic commerce and interactive television	Number news articles x year	Konrad (2006)

Brazil to generate the information needed to construct the Hype Cycle curve. Another option would be based on items in newspapers and magazines. However, these channels allow only word searches, which would not indicate technological maturity stages. Some studies examine the number of technology patents granted, but this would raise a problem in Brazil as the patent examination process is very long-drawn-out, discouraging entrepreneurs. Consequently, scientific papers proved to be the best option, as they allow analyses of technology maturity levels.

The selected terms and the details of the search and extraction from the database (Step 2) are summarized in Table 2. Papers indexed in the WoS database provided input for simulating the Hype Cycle of the selected methodology. All papers by Brazilian institutions published in the WoS database on each technology were taken into consideration, from the earliest publications on each technology through to 2018. Out of all the assessed papers, 2253 were selected for the bibliometric analysis, divided up as follows: 520 on energy storage; 1467 on photovoltaic panels; and 266 on microgrids.

It is worth stressing that, in addition to the search terms shown in Table 2, other search terms were initially entered (both in English and Portuguese) for energy storage as well, such as battery (*bateria*) and flywheel (*volante de inércia*). However, this led to search results that were very broad-ranging, with papers unrelated to the purpose of the survey, describing batteries, capacitors and flywheels. Limiting the search terms to those listed in Table 2 led to results that were more tightly focused, including Compressed Air Energy Storage (CAES), supercapacitors, and Superconducting Magnetic Energy Storage (SMES), among other energy storage technologies.

Although microgrids involve several types of technology, it was

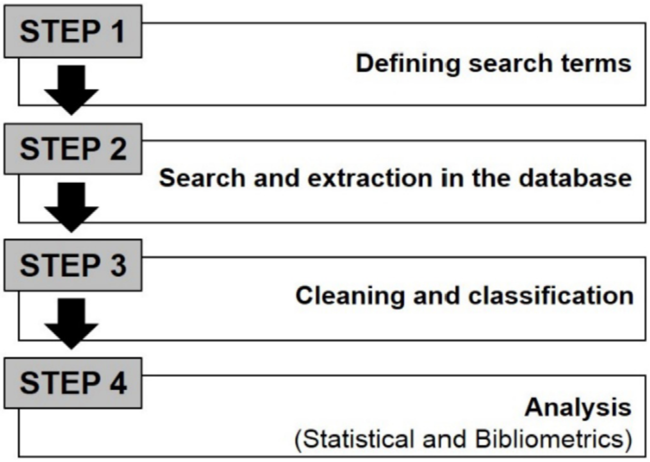


Fig. 1. Search steps.
Source: The authors.

noted that two keywords almost always appeared in papers on this topic – microgrids and distributed energy resources – which is why they were selected as the search terms for microgrids.

Step 3 consisted of a review of papers selected from the WoS database, examining their titles and abstracts in order to check their relevance in terms of indicating technology maturity levels, with the possibility of setting aside any of them whose content was not aligned with the research topic. It should be noted that this stage of the methodology was the most laborious, with more than 2000 papers reviewed.

Step 4 consisted of a statistical analysis of the selected papers and the construction of the Hype Cycle curve. It is worth stressing that this study followed the methodology proposed by Sasaki (2015), as this is a suitable mathematical model for constructing a Hype Cycle curve as required by the purposes of this research project.

3.2. Building the Hype Cycle curve

The methodology indicates that the Hype Cycle is carried out in two stages: Hype Stage and Implementation Stage. The analyzed papers were divided into these two stages, according to their content.

Hype Stage: from Innovation Trigger to Trough of Disillusionment, the curve is bell-shaped, with its X axis representing time and Y axis the non-cumulative number of papers. The number of papers published on the assessed technology provides information for building the Hype Stage.

Table 3
Hype Cycle curve stage functions.

Function	Equation
Logistic	$Y = \frac{a}{1 + b*\exp(-k*X)}$
Gompertz	$Y = a*\exp(-\exp(-k*(X - Xc)))$
Brody	$Y = a*(1 - b*\exp(-k*X))$
Von Bertalanffy	$Y = a*(1 - b*\exp(-k*X))^3$
Richards	$Y = a*(1 - b*\exp(-k*X))^m$

Source: The authors.

Implementation Stage: according to the content of each paper, from Slope of Enlightenment to Plateau of Productivity. This stage may be a sigmoid curve, with time along the X axis and cumulative number of papers along the Y axis, based on the content of each paper. Thus, compliant with the proposed methodology, paper titles and abstracts were analyzed in order to ascertain whether the mentioned technology is actually at the Implementation Stage. Consequently, sentences such as "the implementation of a "prototype", "experimental results" or "implementation of a laboratory" indicate that the technology was still in the implementation stage.

3.3. Curve adjustments

Besides the Logistic and Gompertz Sigmoid (S-shaped) functions used by Sasaki (2015), this paper also analyzes the Brody, Von Bertalanffy and Richards Sigmoid functions, which are summarized in Table 3.

This study applies the functions to each stage separately, as shown in Graph 1-(a). The sigmoid curve of the Hype stage must be turned into a bell-shaped curve, by deriving the function. Combining the two curves after normalization gives a Hype Cycle curve, shown as a dashed line in Graph 1-(b).

3.4. Polynomial adjustment

Polynomial adjustments in the dashed line for 7°–12° were carried out in order to reach the mathematical formulation of the Hype Cycle curve, whose equations are shown in Table 4.

4. Results and discussion

4.1. Results

4.1.1. Energy storage

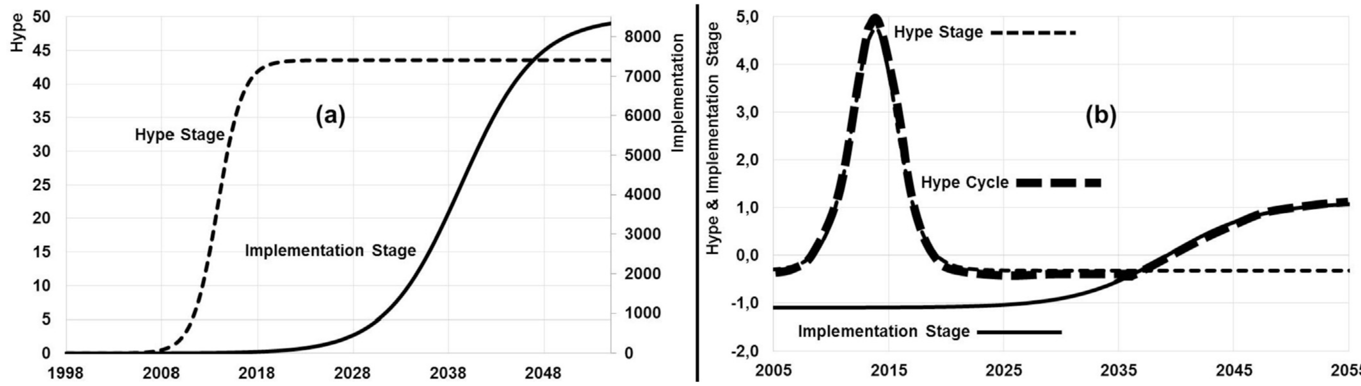
Graph 2 depicts the curves built through the application of the methodology recommended for the energy storage technology in Brazil. The Hype Stage curve represents the non-accumulative

Table 2
Bibliometric survey x technology.

Database: Web of Science
Coverage: All years through to 2018
Search Date: January 10, 2019, 8:00 a.m.
Paper publication location: Brazil

Technology	Description
Energy storage	TS* = ("energy storage*" OR "*armazenamento energia**") AND CU = ("*Brasil*" OR "Brazil")
Photovoltaic distributed generation	TS = ("photovoltaic*" OR "*fotovoltaico**" OR "photovoltaic distributed generation*" OR "*geração fotovoltaica distribuída**") AND CU = ("*Brasil*" OR "Brazil")
Microgrids	TS = ("microgrids*" OR "*microrredes**" OR "distributed energy resources*" OR "*recursos energéticos distribuídos**") AND CU = ("*Brasil*" OR "Brazil")

*TS = Topic, words to be searched in the titles, abstracts and keywords of the papers. CU = country. By searching for "CU", we defined that the paper must have, at least, one author affiliated to the specified country. BY combining "TS to CU" we gathered the papers on the themes published by authors affiliated to Brazilian organizations.
Source: The authors.



Graph 1. The Hype and the Implementation stages (a) and the Hype Cycle (b).
Source: The authors.

Table 4
Polynomial adjustments to the Hype Cycle curve.

Polynomial degree	Equation
7	$Y = intercept + \sum_{i=1}^{7}(Ai*xi)$
8	$Y = intercept + \sum_{i=1}^{8}(Ai*xi)$
9	$Y = intercept + \sum_{i=1}^{9}(Ai*xi)$
10	$Y = intercept + \sum_{i=1}^{10}(Ai*xi)$
11	$Y = intercept + \sum_{i=1}^{11}(Ai*xi)$
12	$Y = intercept + \sum_{i=1}^{12}(Ai*xi)$

Source: The authors.

number of papers on the technology and the Implementation Stage curve corresponds to the cumulative number of papers on the same technology.

By adjusting the sigmoid functions, it became apparent that the Logistic function was the best recorded for the Hype Stage curve ($R^2 = 0.971921$) and the Gompertz function was the best recorded for the Implementation State curve ($R^2 = 0.994415$). Table 5 shows the values of the parameters applied to both functions.

The bell-shaped Hype Cycle curve established for the Hype Stage after normalization and the sigmoid curve established for the Implementation Stage are shown in Graph 3.

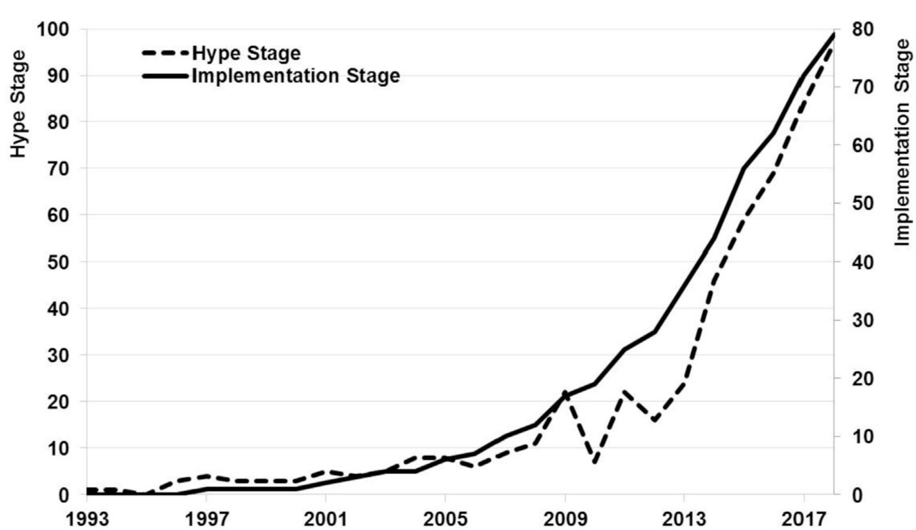
Subsequently, the polynomial adjustment was carried out and the best adjustment was observed in the 12° polynomial function ($R^2 = 0.999012$); taking into account coefficients A_1 to A_{12} and their insertion through the Hype Stage shape, the Hype Cycle curve of the assessed technology was generated (Graph 4).

4.1.2. Photovoltaic distributed generation

Graph 5 shows the curves constructed through applying the suggested methodology for photovoltaic distributed generation in Brazil. The Hype Stage curve represents the number of non-cumulative papers on the technology, while the Implementation Stage curve depicts the cumulative number of papers on this technology.

By adjusting the sigmoid functions, it became apparent that the best adjustments correspond to the Logistic function applied to the Hype Stage ($R^2 = 0.958166$) and the Gompertz function is the best that applied to the Implementation Stage ($R^2 = 0.998164$). Table 6 shows the values recorded for the parameters calculated to assess both functions.

The Hype Cycle curve with a bell curve applied to the Hype Stage and the sigmoid curve used for the Implementation Stage could be

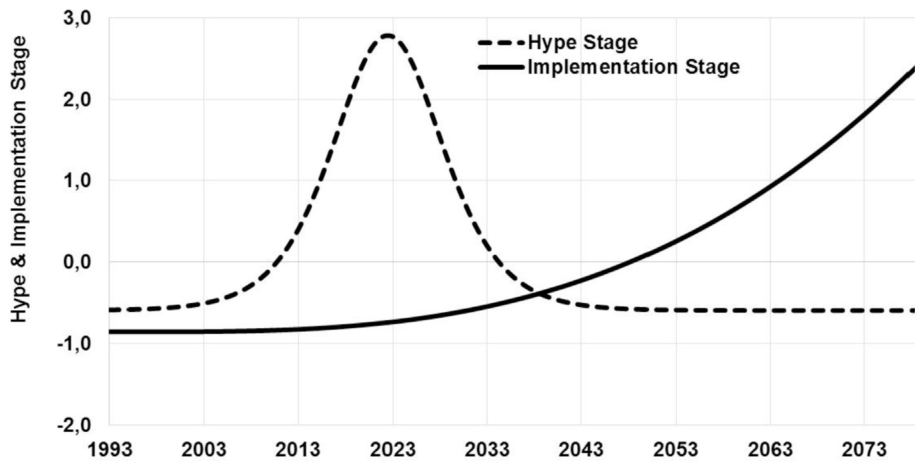


Graph 2. Papers related to energy storage in Brazil indexed in the WoS database. Source: The Authors.

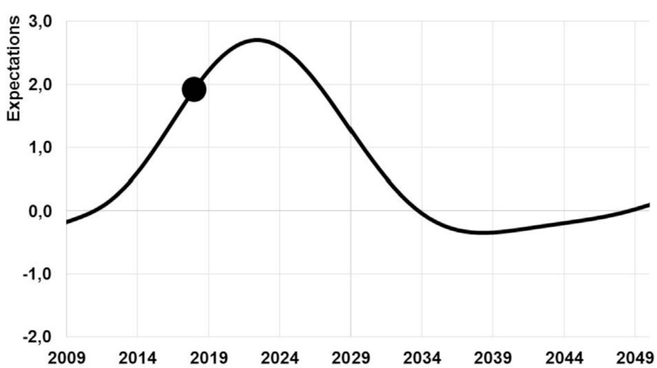
Table 5
Adjustment parameters applied to the Logistic and Gompertz functions in order to assess the energy storage technology.

Adjustment parameters		Value
Hype Stage (Logistic)	*a*	418.096
	b	2580.300
	k	0.258
Implementation Stage (Gompertz)	*a*	168657.883
	k	0.021
	Xc	119.943

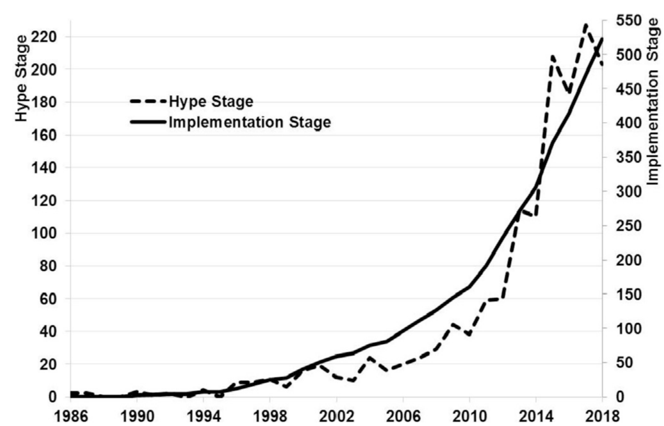
Source: The Authors.



Graph 3. Bell-shaped and sigmoid curves established for energy storage after normalization.
Source: The Authors.



Graph 4. Hype Cycle curve established for energy storage in Brazil.
Source: The Authors.



Graph 5. Papers on photovoltaic distributed generation in Brazil indexed in the WoS database.
Source: The Authors.

found after normalization (Graph 6).

Subsequently, the polynomial adjustments were introduced and the best adjustment was obtained through the 11° function ($R^2 = 0.984270$); taking into account coefficients A_1 to A_{11} and their intersection, the hype Cycle curve was generated for the technology under analysis, as shown, as shown in Graph 7.

4.1.3. Microgrids

Graph 8 shows the spread for microgrids in Brazil. The curve established for the Hype Stage represents the number of non-cumulative papers on the technology and the curve established for the Implementation Stage corresponds to the cumulative number of papers on this technology.

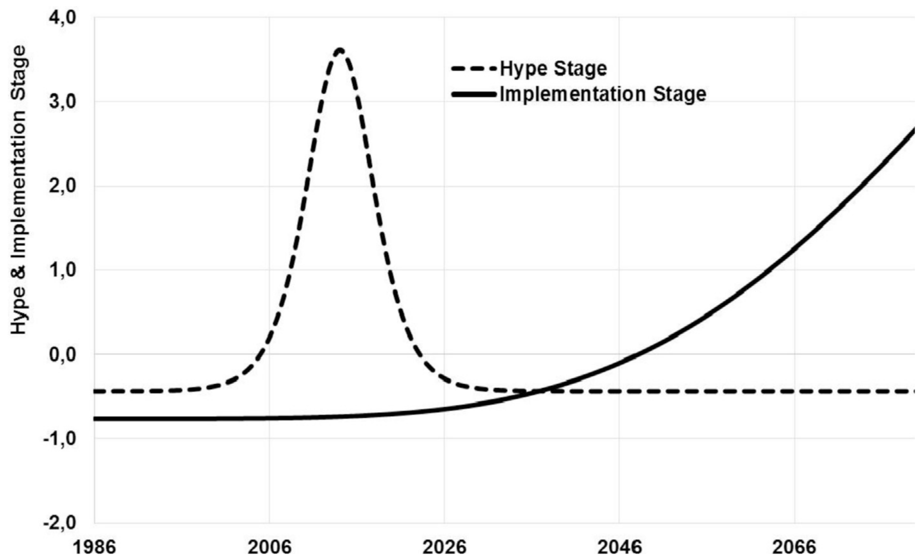
By adjusting the sigmoid functions, it became apparent that best adjustments were observed in the Logistic Function applied to the Hype Stage ($R^2 = 0.893664$) and the best adjustment in the Gompertz function was that applied to the Implementation Stage ($R^2 = 0.976012$). Table 7 shows the values recorded for the parameters calculated for both functions.

The Hype Cycle curve with bell curve for the Hype Stage and with sigmoid curve for the Implementation Stage after normalization was generated (Graph 9). Subsequently, the polynomial adjustment was carried out and the best adjustment was observed through the 12° ($R^2 = 0.886563$); taking into consideration coefficients A_1 to A_{12}, and their intersection, the Hype Cycle curve was drawn for the technology under analysis, as shown in Graph 10.

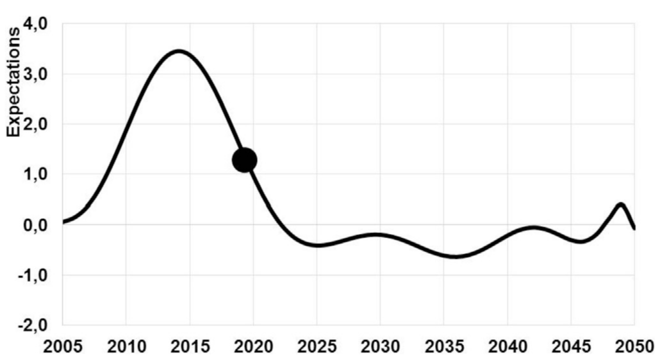
Table 6
Adjustment parameters of the Logistic and Gompertz functions applied to the photovoltaic distributed generation.

Adjustment parameters		Value
Hype Stage (Logistic)	*a*	275.286
	b	82728.850
	k	0.390
Implementation Stage (Gompertz)	*a*	174573.631
	k	0.022
	Xc	113.679

Source: The Authors.



Graph 6. Bell-shaped curve and sigmoid curve applied to photovoltaic distributed generation (after normalization).
Source: The Authors.



Graph 7. Hype Cycle curve generated for photovoltaic distributed generation in Brazil.
Source: The Authors.

4.2. Discussion

The research project focused on CleanTech startups in Brazil shows that several of them are still in the development stage, and have not yet reached their break-even points[4] (operating margins remain in the red for 39% of the mapped companies). This issue indicates that CleanTech enterprises generally require heavy investments.

[4] The point at which a business starts to make as much money as it has spent on a particular product, activity, etc.

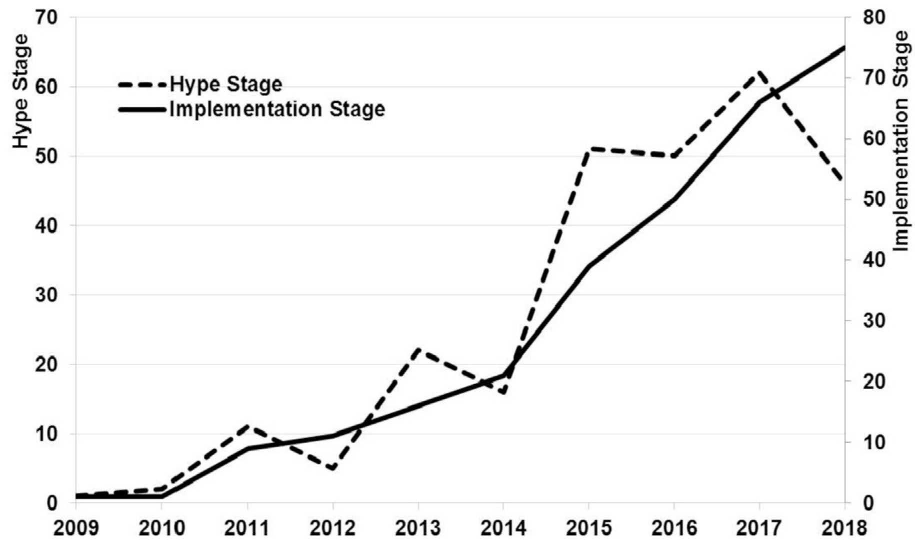
In Brazil, major energy utilities have allocated few investments to changing this situation. Strategies requiring in-depth discussions (corporate venture capital and joint ventures/acquisitions) are rare, with over 60% of the mapped CleanTech startups unable to access the financial services needed to expand their businesses.

More information is needed on the CleanTech startups ecosystem, particularly the technologies that they offer, in order to define their development levels. In the energy sector, credibility is a major indicator, as tightly-regulated utilities might run the risk of their investments not being acknowledged by the regulator, in some cases. It is thus quite clear that the Hype Cycle curve could well allow their managers to take correct decisions on the technologies that must be taken into consideration, based on knowledge of their status and trends.

Another issue raised by the study is the trend towards CleanTech startups clustering in the solar power and energy storage subsegments in Brazil. These two technologies are extremely important for reducing greenhouse gas emissions by the power sector, making it steadily more environmentally friendly, as energy storage can supplement electricity generation through intermittent sources such as wind and solar power.

Worldwide, the countries with more distributed energy storage facilities in 2017 were the USA, Germany, Japan and Australia. Furthermore, the installed capacity of this type of system should expand globally by 684 MW in 2017 to 19,699 MW in 2026 (NAVIGANT, 2017).

However, the expansion of this technology is still incipient in Brazil. The illustrated Hype Cycle curve identifies the status of energy storage in Brazil. All over the world, this technology is

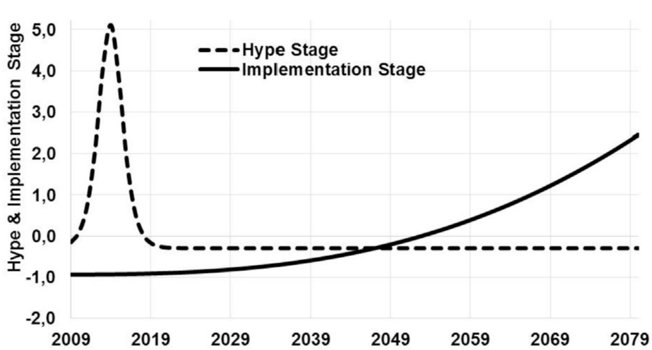


Graph 8. Papers related to microgrids in Brazil indexed in the WoS database.
Source: The Authors.

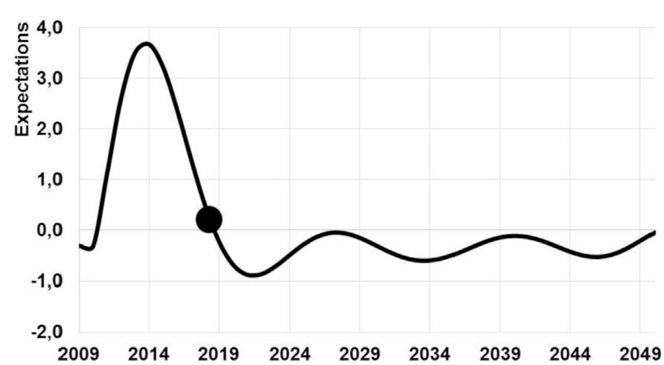
Table 7
Adjustment parameters applied to the Logistic and Gompertz functions established for the microgrids.

Adjustment parameters		Value
Hype Stage (Logistic)	*a*	56.359
	b	397.663
	k	1.009
Implementation Stage (Gompertz)	*a*	61556.208
	k	0.041
	Xc	55.999

Source: The Authors.



Graph 9. Bell-shaped curve and sigmoid curve established for the microgrid after normalization.
Source: The Authors.



Graph 10. Hype Cycle Curve established for microgrids in Brazil.
Source: The Authors.

becoming an option that is increasingly more feasible at the technical and economic levels, particularly as a distributed resource, as stressed in the previous paragraph.

Research on energy storage in Brazil was focused on off-grid systems; however, given the expansion of renewables in both generation and distribution, local research projects now include interconnected systems. This even forced the Brazilian regulatory body (ANEEL) to launch a specific R&D program[5] in 2016, in order to assess this technology and introduce it in Brazil.

The Hype Cycle curve shows that energy storage technologies tend to lag slightly in terms of maturity, compared to photovoltaic panels and microgrids. Energy storage is nearing the Peak of Inflated Expectations Stage, meaning that the expectations of this technology will still rise, drived by R&D findings.

It is essential to note that if research were to evaluate different energy storage technologies, each of these assessments could present different outcomes, as the technologies might be at different maturity stages. In general, there are several barriers — technological, regulatory, economic or market-related — that are curbing or curtailing the deployment of energy storage technologies and the establishment of their markets, as shown in Table 8.

[5] ANEEL R&D N. 21/2016 (under development): Technical and Commercial arrangements in the power storage systems in the Brazilian Power Generation Sector. Projects are expected to be finished in the first half of 2021.

Table 8
Barriers to energy storage deployment in Brazil.

Regulatory	Energy storage definition
	Uncertainty about asset ownership and operation
	Rule discrepancies among segments
	Administrative issues
Economic	High costs
	Lack of revenue compensation mechanisms
	Lack of funding models
Market	Lack of ancillary services market
	Lack of price signals (tariffs)
	Uncertainty and risks in business models

Source: The Authors.

Photovoltaic panel technology is an option that is becoming increasingly more feasible at the technical and economic levels, with a 68% drop in average installation costs between 2010 and 2017, while panel efficiency rose from 4.5% in the 1950s to 15% today (IRENA, 2018).

Rising efficiency and dropping costs were buttressing significant growth for the global distributed photovoltaic market, particularly in countries such as Germany, the USA, China and Japan. By 2024, this market is expected to reach an installed capacity of 346.1 GW, with industry-wide revenues of USD 668.5 billion (NAVIGANT, 2015).

Although used for several decades in countries such as Germany, the USA, China and Japan, this technology put down firm roots in Brazil only in 2011, when local regulator (ANEEL) set up a specific R&D project in order to assess its possibilities, prior to its introduction.[6] Subsequently, a regulatory framework was drawn up for these systems,[7] which is still being fine-tuned.[8] The assessed papers address research focused on the development of photovoltaic systems in Brazil, particularly for enhancing their performance. Rising numbers of research projects reflect government intentions of ensuring the feasibility of the photovoltaic industry. However, this process did not follow the technological paths pursued by other countries, still importing solar panels for installation in Brazil. As a result, this technology is heavily dependent on imports of most of its main components, with its use expanding as international costs decrease. However, according to Technical Report 56–2017 published by ANEEL, market expansion forecasts shrank by some 30% through to 2024.

The Hype Cycle curve for microgrids reflects its status in Brazil, in graphic terms. Worldwide, this technology is an option that is becoming increasingly more feasible at the technical and economic levels. However, similar to photovoltaic panels, it is currently in the Trough of Disillusionment Stage in Brazil.

The assessed papers address research focused on the development of some components such as inverters, controllers and other devices. Although studies have demonstrated solutions for overcoming technological barriers, there are critical economic, market and above all regulatory issues that our undermining the feasibility of microgrid expansion. Absent any solid proposals changing the regulatory framework in order to favor microgrids, research in this technological field falls well short of what is required.

Some of the main hurdles hampering the implementation of microgrids in Brazil are: high investment costs; lack of financing mechanisms; ban on sales of their services and/or products; lack of capitalization; lack of definition of their characteristics in the regulatory framework (islanding and reconnection, power generation and energy sales); connection rules (not acknowledged); concession areas (would not allow the implementation of some microgrid types) and tariff mechanisms (tariffs reflecting their respective costs and benefits) (Bellido et al., 2018).

In addition to establishing an appropriate regulatory framework, better development of distributed photovoltaic generation is expected (generally distributed generation), together with energy storage technologies (based on the findings released in ANEEL R&D 21/2016), thus boosting the development of microgrids in Brazil.

5. Conclusions

This study researches the development levels of three emerging technologies in the Brazilian power sector: energy storage, photovoltaic panels and microgrids. CleanTechs are vital, as they can enhance the reliability, quality, generation and distribution of clean electricity, postponing investments in infrastructure upgrades and modernization. In order to do so, mathematical functions were used to build the Hype Cycle curve for each of these technologies.

Based on the results, photovoltaic panels and microgrids are in the Trough of Disillusionment stage, with market expectations slumping and few applications for these technologies, with limited hands-on experience leading to their disappearance at scientific and business scales. Although technical issues are being assessed, these technologies still face economic, market and regulatory barriers that discourage their use and expansion. However, these technologies could develop a keener competitive edge over the short and medium terms if the regulatory environment for the other three dimensions could be changed. Ripe for development, they are close to the Slope of Enlightenment stage.

Energy storage technology is currently in its Hype Cycle growth and acceptance stage, between the first (innovators) and second (acceptors) stages. There is a possibility that its acceptance may result in future financial losses, thus leading to the conclusion that the technology has not yet reached the Peak of Inflated Expectations stage, indicating that its core concept cannot yet be considered at the business scale.

Similar to photovoltaic panels and microgrids, energy storage technologies are still faced by economic, market and regulatory hurdles (in addition to technical barriers) that must be carefully studied in order to tailor them to the needs of these technologies.

The development of distributed generation through photovoltaic panels might well spur energy storage technologies, in order to even out intermittent renewable generation. In turn, burgeoning development of these technologies could well boost faster microgrid expansion, as a major component.

Although the assessed technologies are not following global majority trends, it is notable that they are not starting up from the Innovation Trigger stage, as they are already endowed with a certain level of maturity elsewhere in the world, thus influencing their maturity in Brazil. Furthermore, rural electrification programs dating back decades have already endowed Brazil with the know-how needed by these technologies.

It is important to stress that the government should implement more systematic policies supporting innovation, thus speeding up their adoption and encouraging companies to engage in this process, pursuing further development and higher income generation levels. In fact, innovation should be ranked as a fundamental factor for upgrading the quality of Brazilian industry as a whole.

This study describes a way to measure the Hype Cycle and some important findings on for the technologies under examination, indicating good possibilities for further research projects exploring the life-cycles of other technologies.

Despite the benefits and advantages of the Hype Cycle curve,

[6] R&D 13/2011: Technical and commercial arrangements for photovoltaic generation introduction in the Brazilian Energy Matrix.

[7] REN 482/2012: Establishes regulatory framework for distributed micro and mini generation in the electricity distribution system and the net metering.

[8] In 2015, the REN 482/2012 was last modified by REN 687/2015.

one of the criticisms of this tool relates to the definition of the Y and X axes (Steinert and Leifer, 2010). Blending bell-shaped and sigmoid curves (measuring different phenomena),[9] may not be handled simply through a mathematical equation (definition of the Y axis).

In terms of defining the X axis in order to assess technology performance (sigmoid curve), the R&D effort or expenditure variable may be used instead of the time variable, as this has a greater influence on technology performance.

Based on the issues raised, and in order to continue this project, further research is needed, such as: (***i***) the possibility of using tools other than the Hype Cycle curve, in order to assess technologies and their use; and (***ii***) use documents other than scientific papers (such as industrial and government reports, patents and news items) in order to assess their impact on the development of the Hype Cycle curve.

Funding

This study also received financial support from the Coordination for the Improvement of Higher Education Personnel (CAPES) and the National Council for Scientific and Technological Development (CNPq).

Acknowledgements

This study was conducted under the aegis of the Research and Technological Development Program for the Electricity Sector subject to the Brazilian Regulator (ANEEL), as part of the R&D project exploring the Impacts of the Cleantech Startups Ecosystem on the Brazilian Power Sector, funded by EDP.

References

Adamuthe, A.C., Tomke, J.V., Thampi, G.T., 2015. An empirical analysis of hype cycle: a case study of cloud computing technologies. International Journal of Advanced Research in Computer and Communication Engineering 4 (10), 316–323.
Azizian, N., Sarkani, S., Mazzuchi, T.A., 2009. Comprehensive review and analysis of maturity assessment approaches for improved decision support to achieve efficient defense acquisition. Proceedings of the world congress on engineering and computer science. In: WCECS 2009. San Francisco, United States, vol. II, 2009.
Bellido, M.H., Pinguelli, L., Pereira, A., Mosqueira, D., Kahn, S., 2018. Barriers, challenges and opportunities for microgrid implementation: the case of Federal University of Rio de Janeiro. J. Clean. Prod. 188, 203–216.
Budde, B., Alkemade, F., Hekkert, M., 2015. On the relation between communication and innovation activities: a comparison of hybrid electric and fuel cell vehicles. Environmental Innovation and Societal Transitions 14, 45–49.
Dedehayir, O., Steinert, M., 2016. The hype cycle model: a review and future directions. Technol. Forecast. Soc. Chang. 108, 28–41.
Fenn, J., Raskinno, M., 2008. Mastering the Hype Cycle: How to Choose the Right Innovation at the Right Time, 1 ed. Harvard Business Press, United States.
Gaddy, B.E., Sivaram, V., Jones, T.B., Wayman, L., 2017. Venture Capital and Cleantech: the wrong model for energy innovation. Energy Policy 102, 385–395.
Garousi, V., 2012. Classification and trend analysis of UML books (1997-2009). Softw. Syst. Model. 2 (11), 273–285.
Gartner, 2018. Hype Cycle for Emerging Technologies 2018.
Gray, G.L., Chiu, V., Liu, Q., Li, P., 2014. The expert systems life cycle in AIS research: what does it mean for future AIS research? Int. J. Account. Inf. Syst. 15, 423–451.
IRENA, 2018. Renewable Power Generation Costs in 2017. International Renewable Energy Agency, Abu Dhabi.
Jarvenpaa, H.M., Makinen, S.J., 2008a. An empirical study of the existence of the hype cycle: a case of DVD technology. In: IEEE International Engineering Management Conference. Estoril, Portugal, 2008.
Jarvenpaa, H.M., Makinen, S.J., 2008b. Empirically detecting the hype cycle with the life cycle indicators: an exploratory analysis of three technologies. In: IEEE International Conference on Industrial Engineering and Engineering Management, Singapore, 2008.
Jun, S., 2012. A comparative study of hype cycles among actors within the socio-technical system: with a focus on the case study of hybrid cars. Technol. Forecast. Soc. Chang. 79, 1413–1430.
Jun, S., 2012. An empirical study of users' hype cycle based on search traffic: the case study on hybrid cars. Scientometrics 91, 81–99.
Kachan, D., Fugere, D., 2013. Cleantech Redefined - why the next wave of cleantech infrastructure, technology and services will thrive in the twenty first century. Available at: http://www.kachan.com/report/cleantech-redefined. accessed: 20.03.17.
Khodayari, M., Aslani, A., 2018. Analysis of the energy storage technology using Hype Cycle approach. Sustainable Energy Technologies and Assessments 25, 60–74.
Kim, J., Hwang, M., Jeong, D., Jung, H., 2012. Technology trends analysis and forecasting application based on decision tree and statistical feature analysis. Expert Syst. Appl. 39, 12618–12625.
Konrad, K., Markard, J., Ruef, A., Truffer, B., 2012. Strategic responses to fuel cell hype and disappointment. Technol. Forecast. Soc. Chang. 79, 1084–1098.
Konrad, K., 2006. The social dynamics of expectations: the interaction of collective and actor-specific expectations on electronic commerce and interactive television. Technol. Anal. Strateg. Manag. 3 (18), 429–444.
Lente, H., Spitters, C., Peine, A., 2013. Comparing technological hype cycles: towards a theory. Technol. Forecast. Soc. Chang. 80, 1615–1628.
Linden, A., Fenn, J., 2003. Strategic analysis report: understanding gartner's hype cycles. Available at: https://www.bus.umich.edu/KresgePublic/Journals/Gartner/research/115200/115274/115274.pdf. accessed: 10.04.2017.
Mendonça, H.L., 2017. O impacto das startups no setor de energia (Portuguese). Available at: https://bibliotecadigital.fgv.br/dspace/bitstream/handle/10438/19278/Coluna%20Opiniao%20Setembro%20-%20Hudson.pdf. accessed: 20.12.18.
Montalvo, C., Kemp, R., 2008. Cleaner technology diffusion: case studies, modeling and policy. J. Clean. Prod. 1 (16), S1–S6.
NAVIGANT, 2017. Executive Summary: Country Forecasts for Distributed Energy Storage 2Q 2017. Navigant Research, United States.
NAVIGANT, 2015. Executive Summary: Distributed Solar PV Published 3Q 2015. Navigant Research, United States.
Ruef, A., Markard, J., 2010. What happens after a Hype? How changing expectations affected innovation activities in the case of stationary fuel cells. Technol. Anal. Strateg. Manag. 3 (22), 317–338.
Salim, H.K., Stewart, R.A., Sahin, O., Dudley, M., 2019. Drivers, barriers and enablers to end-of-life management of solar photovoltaic and battery energy storage systems: a systematic literature review. J. Clean. Prod. 211, 537–554.
Sasaki, H., 2015. Simulating Hype Cycle curves with mathematical functions: some examples of high-tech trends in Japan. Int. J. Manag. Inf. Technol. 2 (7), 1–12.
Steinert, M., Leifer, L., 2010. Scrutinizing gartner's hype cycle approach. In: PICMET 2010 Proceedings, July 18-22, Phuket, Thailand, Vol. 1. ., pp. 254–266

[9] Bell-shaped curve based on the human being, the expectations/hype of his sudden irrational positive reaction to the introduction of new technologies and a sigmoid curve based on the notion of technology performance.