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New indicator for measuring the environmental sustainability of publicly traded companies: An innovation for the IPAT approach

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ABSTRACT

The present study aimed to present a conceptual and practical overview of IPAT and a remodeling of the indicator, making it applicable to publicly traded companies as a new methodology to measure their environmental performance through the IPAT-e indicator, constituting information to support investment decisions in stock exchanges. The new approach, here called IPAT-e, consists of adapting the IPAT equation for its application to the business environment, allowing to measure the degree of sustainability of companies, considering their impact from their water consumption, atmospheric emissions, effluents emissions, energy consumption and solid waste generation. Companies part of the corporate sustainability (ISE) and the efficient carbon (ICO_2) indices of the Brazilian stock exchange (BM&FBovespa) are the objects of this study. Data were collected after ICO_2 came into effect in 2010 and comprised the period from 2010 to 2015. In this criterion, seven companies were selected: Braskem, BR Food, Fibria, Klabin, Natura, Suzano and Vale. The index was effective in assessing production technological efficiency, allowing to identify which variables were causing impact over a period. That, associated with elasticity calculation, allowed analyzing the influence of production on variables that caused impact, depending on the degree of technology adopted by the company.

1. Introduction

The planet experiences a period called Anthropocene, a geological era in which human beings exert dominion over the Earth, appropriating themselves of resources and environmental services made available by the ecosystem (Fischer-Kowalski et al., 2014). This has brought incalculable losses and has been destabilizing natural environment. Population growth, with its consequent human consumption patterns diversification, has caused impacts never seen before. By following this course, they will make finite resources reach their maximum level of degradation and environments lose their resilience capability (Fischer-Kowalski et al., 2014).

When degrading action effects become more evident, humanity initiates its search for the restoration of the balance needed for maintaining its existence on Earth. Such a pursuit culminated in the measuring of sustainability patters in the beginning of the decade 1970, with the appearing of the equation Impact = Population x Affluence (represented by population resources consumption level) x Technology (IPAT), which components translate mathematically the relation between number of inhabitants, environmental impact and technological innovation (Trauger et al., 2003).

The IPAT equation, presented for the first time in the decade 1970, resulted from discussions between scientists Barry Commoner, Paul Ehrlich and John Holdren. In the light of those discussions, the authors conceived and identified three factors that

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helped determine the Human Environmental Impact by using the equation formula $I = P x A x T$, with Impact (I), Population (P), Affluence (A) and Technology (T) (Chertow, 2008). That approach was founded on population consumption and environmental impact.

Industrial Ecology scholars include the private industry as an active element in the discussion of environmental impacts. Lifset (1997) considers businesses as key actors in environmental protection, especially those that adopt technological innovations environmental performance assessment methods including products and processes. In this context, there is an increasing concern related to the environmental quality resulting from a worldwide fast production and consumption expansion associated to products short life cycles (Lifset, 2000).

A problem raised and discussed involved the responsibility of companies with regard to their activities and environmental impacts caused by them and associated with population growth, which increased consumption and production levels. That discussion could lead, thus, to the measurement of how much companies were assuming their actual responsibility and the influence of their actions on impact reduction.

In the face of the responsibility attributed to companies, the challenge found in measuring corporate environmental sustainability and the need to develop an IPAT variant that contributed to such measuring, an adaptation of the equation became necessary to assess the degree of environmental sustainability of companies, in particular those listed in the Brazilian Stock Exchange sustainability indices (BM&FBovespa, 2016).

Docekalová et al. (2017) holds that developing sustainability indicators requires competencies on the viability of the systems involved and their contributions to sustainability, as new tools for measuring are needed.

In this context, the present study aimed to present a panorama both conceptual and of practical applications of IPAT, associated with a remodelling of the indicator, making it applicable to companies as a new methodology for gauging their environmental performance. Such procedure was made possible through the IPAT-e indicator, constituting additional information to subsidize investments decisions in stock exchanges.

2. IPAT: conceptual panorama and practical applications

Generally credited to Ehrlich and Holdren (1972), the index stands out for its simplicity in the face of an infinity of more complex sustainability indicators models. It is also a paradigm chosen by many scholars as a starting point to investigate population interactions, economic growth and technological development (Chertow, 2008). Studies demonstrate which IPAT equation variants have generated greater impact on the sustainability of a particular region researched, as well as which equation element generates the most impact in the natural world, or most contributes to balance restoration. Highlights are those conducted by Commoner et al. (1971), Ehrlich and Holdren (1971) and Ehrlich and Holdren (1972), who initiated the discussion, followed by Harrison (1992), Heaton et al. (1991) and Mackellar et al. (1995). Chertow (2008) made later on a general retrospect related to the discussion on IPAT. The most recent discussions have been presented by Jowett and Izazola (2010), Raven (2012) and Fischer-Kowalski et al. (2014).

Evidences suggest that the IPAT equation can be used to give support to different points of view (Chertow, 2008; Ehrlich and Holdren, 1971). On that note, divergent argumentations emerge regarding technology as damaging in the Faustian view (Commoner, 1972). On the other hand, Simon and Khan (1984), among others, understand population growth and wealth as driving forces of technological development.

Nations with a large number of inhabitants, such as some countries in Asia and sub-Saharan Africa, are not able to produce everything their population needs and, if these countries reached that production level, in order to follow developed countries patterns, there would be an even greater increase in waste production and in the carrying capacity of the Earth, as Gans and Jost consider (2005). These and other reasons confirm the IPAT equation premise that population growth is the main source of environment degradation.

Considering that the IPAT equation analysis shall not ground on a single point of view due to the complexity and amplitude of variables included in the equation (Sherbinin et al., 2007), it is important to remember that since its conception some criticisms have occurred. Among them are those of scholars that identified some flaw or the need of additions to the equation, aiming to make it more wide-ranging and effective (Wexler, 1996; Giambona et al., 2005; Courtice, 2010).

Although initially used to quantify contributions to unsustainability, there has been a reinterpretation of the equation in order to assess the most promising way into sustainability (Chertow, 2008). The impact calculated through IPAT is not the actual environmental impact, but it considers the used or produced resources amount as well as pollution as a proxy for environmental damage. It furthermore takes into account that the three equation variables are always changing in their relations with one another (Raven, 2012). For example, the consumption of a particular resource may grow, but technological advances can decrease the environmental impact of an increased consumption. Consumer trends and choices can also affect environmental impact.

Dietz and Rosa (1994), Waggoner and Ausubel (2002), and Stewart (2014) carried out studies that represented an evolution to the IPAT formulation, accounting for the fact of its excessive simplicity and the need to broaden the equation credibility from its initial formulation by Commoner et al. (1971) and Ehrlich and Holdren (1972). Those studies added variables to the formulation, creating what Chertow (2008) called "equation variants", applying statistical and econometric models, and expanding it for its usage in other areas, such as industrial ecology.

The theoretical foundations and the interpretation of empirical applications carried out by scholars of IPAT are controversial, according to Gans and Jost (2005). The authors agree with the fact that the IPAT equation is simple and represents a starting point that needs to be broadened and decomposed, looking for foundations in the econometric analysis and in the stochastic formulation of Dietz and Rosa (1997). There is a recognition that there is no simplistic way of bypassing a solid economic modelling when estimating population growth impact for environmental purposes.

In a similar approach, Sherbinin et al. (2007) report criticisms related to the fact that IPAT does not estimate interactions between terms (for example, a rise in affluence can lead to more efficient technologies) and, as a result, it omits reference to important variables, such as culture and institutions (i. e., social organization). Thus, the impact is not linearly related to its variables (where there could be important thresholds) and that leads to erroneous conclusions.

In this way, they conclude that a new generation of IPAT modeling is necessary to explicitly explain interactions between its components, including the reciprocal impacts of environmental changes on the population dynamics as part of an integrated assessment modeling; that is, an innovation to the IPAT equation is necessary for it to become applicable to business entities that seek to achieve sustainability, constituting an eco-innovation instrument as defined by the European Commission (EC, 2008).

3. Business sustainability

Companies have a social function and the moment their activity, by virtue of their organization, begins to merit such designation, it inevitably becomes an essential link in the environment balance chain as a whole (Silva, 2003), which has not happened in practice. Putt Del Pino et al. (2016) argue that, if ambitious measures are not implemented to reduce greenhouse effect gases emissions, the world will head for a catastrophic rise of 6 degree Celsius in global average temperature until the end of this century. Furthermore, the authors reminds us that only 15% of forests remain intact, and that over the last decade, more than one billion people were living in regions with water scarcity.

According to Brandão and Santos (2007), the approach of businesses in the light of sustainability allows companies to consider in a more structured way the local and global aspects that are increasingly affecting their economic-financial results. It also allows them to respond to society's new demands in matters as for environment, social justice and those appertaining future generations. On the other hand, Bocken et al. (2014) argue that in the current scenery of a rising global population that accelerates global development and increases the use of resources as well as the associated environmental impacts, it seems increasingly evident that usual business models are not an option for a sustainable future.

Sustainability has been pursued by public-traded companies, non-profit organizations and the public power, but to measure how much an institution is being sustainable or looking for sustainable growth is not an easy task. As a result, Elkington (2004) created the Triple Bottom Line (TBL) concept in the mid-1990's, an accounting concept that goes beyond profits traditional measures, return on investment and stockholder value.

Triple Bottom Line advances toward environmental and social dimensions, seeking to demonstrate sustainability as a result of the balance within economic, environmental and social (which reflect social equity or social justice) indicators of an organization, with focus on seven revolutions considered to be of market, values, transparency, life cycle technologies, partners, time and corporate governance, reaffirmed by Stubbs and Cocklin (2008) in a study on sustainable businesses models archetypes.

In a systemic view of sustainability, for which economic, environmental and social indicators are interdependent, its analysis implies great challenges, mainly in how to measure the degree of sustainability with indicators that are robust and that may enable business prosperity in future scenarios (Lavorato, 2016). Hence, sustainability is a mandatory component in companies, without which they will become economic and financially unviable in the long term.

Considering an integrated view under the economic-financial result perspective, it is assumed that the more consistent and wide the perception of those involved with sustainability on the part of the company, the greater its viability. Sustainability affects revenues, costs, expenses, investments and capital costs, and it has considerable impact on intangible assets, mainly on the brand, which will be associated with the idea of a company that concerns, protects, conserves or that solely explores and destroys the surrounding environment.

In this sense, Bhat (1998) concluded that a company's greater environmental compliance produces greater profit, and the rigidity of environmental legislations forces companies to seek innovation, which can increase production and competitiveness. Al-Tuwaijri et al. (2004) concluded that "**good**" environmental performance is associated with "**good**" economic performance. That ties in with the studies of Hassan and Romily (2018), wherein lower emissions are associated with better corporate economic performance.

Businesses sustainability, in regard to their attitude towards external (legislation and regulations in force) and internal (integration to the company's strategy or principals and aims) stimuli, can be classified according to sustainability stages (Brandão and Santos, 2007), in which the fourth and fifth stages are the most important, once they include not only the obligation of legal compliance, but also consider sustainability a strategy integrated with the company's businesses in a single system, as discussed by Boons et al. (2013), and Boons and Lüdeke-Freund (2013) in a special edition on sustainable business model, published in 2013 by Journal of Cleaner Production.

3.1. Business sustainability in stock exchanges

The construction of sustainability indices in the stock exchange emerges along with the environmental matter and constitutes a preponderant factor in the search for business sustainability within the capital market ambit. From the 1980's onwards, the world watched an unprecedented expansion of stock exchange businesses, when shares transactions gained speed in global markets due to technological evolution (Marcondes and Bacarji, 2010). Thus, the world entered a globalization effective process that brought positive and negative influence to the environment, making the decade 1980-90 a milestone for initiatives related to environmental matters.

As a favorable movement towards environment and development was arising, the first funds of Socially Responsible Investment (SRI) were created. In total, the generation of three funds occurred as the search for sustainability gained amplitude (Marcondes and Bacarji, 2010).

The authors remind us that the first generation entailed funds that excluded from their portfolio shares of companies that maintained a relationship with the *apartheid* regime in South Africa or who participated in the weapons supply chain for the Vietnam War. The second generation encompassed funds aligned with the sustainability movement that began to permeate global society from the emergence of the concept of eco-efficiency and clean production, and the regulation by the public sector. The third generation involved funds aligned with companies that started understanding that they should be protagonists in the search for more sustainable models of development. The apex of this global trend was the appearing of capital markets monitoring indices that had as their foundation the performance of stocks of the companies most committed to the environment.

Currently, eighteen stock exchanges possess sustainability indices worldwide. The pioneer was New York's, which created the Dow Jones Sustainability Indexes (DJSI) in 1999. Following the same trend, the London Stock Exchange created the Financial Times Stock Exchange (FTSE4Good) in 2001. Afterwards, in 2003, the Johannesburg Stock Exchange (JSE) adhered in Johannesburg, South Africa, followed by BM&FBovespa in 2005, which became the fourth stock exchange in the world to implement a Corporate Sustainability Index (ISE).

The main and common characteristic of the indices is that companies adhere voluntarily and are aware that sustainability is a condition for keeping themselves competitive in the market. They also know that society's expectations of them have been increasing, since they compete in an environment with scarce resources and with global threats to the maintenance of life support on the Earth.

As for stock markets, Stekelenburg et al. (2015), in their study in Europe, concluded that the market rewards companies with high levels of sustainability performance. Furthermore, Xiao et al. (2018) have recently suggested sustainability management as a source of competitive advantage for companies located in emerging and developing countries.

3.2. BM&FBovespa ISE

With the corporative world dynamics, attention to sustainability becomes imperative, leading BM&FBovespa to become in 2004 the first stock exchange in the world signatory of the United Nations Global Compact of Sustainability, launching the Brazilian Corporate Sustainability Index (ISE) in 2005 and becoming one of the main global references in management and business governance indicators, according to Marcondes and Bacarji (2010). With the emergence of atmospheric pollutant emissions, and following a global trend, BM&FBovespa also launched the Efficient Carbon Index (ICO_2) in 2010.

The ISE index follows the premises of Triple Bottom Line. It is constituted on the basis of corporate governance indicators and has environmental, economic and social dimensions as inseparable priorities. Data are obtained for selection through the application of a questionnaire elaborated by the Sustainability Studies Center of the Getúlio Vargas Foundation and via documentary analysis of the company. *Klynveld Peat Marwick Gesellschaft (*KPMG), a company of independent auditors, lend veracity to information, guaranteeing stock exchange credibility with the market (BM&FBovespa, 2015).

The methodology adopted by BM&FBovespa involves quantitative analysis (questionnaire scores) and qualitative analysis (documents verification). The questionnaire contains queries related to seven dimensions, namely general, corporate governance, environmental, social, economic-financial, climatic changes and nature of products. Besides questionnaire application, the sending of evidences occurs, which is audited by KPMG. Within each dimension, there are established evaluation criteria and indicators that are considered during analyses.

Questionnaire answers are submitted to a software that analyzes three criteria. The first analysis is of the standard deviation of the set of companies. In the second, deviation variance, and maximum and minimum points are defined. The third contemplates the ISE evaluation methodology which is the cluster analysis, grouping companies according to the distance between their scores and approximating those that register the smallest Euclidean distance between their scores (grouping the ones similar among themselves).

Another sustainability index is a joint initiative of the National Bank for Economic and Social Development (BNDES, Brazil) and BM&FBovespa. It is the Efficient Carbon Index (ICO_2), which aims to indicate the average performance of quotations of assets belonging to the IBrX50 portfolio of BM&FBovespa, taking into account companies' greenhouse gases (GHG) emissions.

Three of the criteria for inclusion of companies are listed in the ICO_2 index (BM&FBovespa, 2015): *i)* to belong to the IBrX50 portfolio; *ii)* to formally adhere to the ICO_2 initiative and *iii)* to report data of their annual greenhouse gases (GHG) inventory according to range level and deadlines defined by BM&FBovespa. The company also informs the calendar-year revenue for the emission/revenue coefficient calculation, as follows:

$$Emission/Revenue\ Coefficient\ \ t = \ (Emission\ of\ GHGt(tCO2e))/Revenuet\ \ \text{in R\$ millions of } reais.$$

Where:

Emission of $GHG_{\mathbf{t}}$ = quantity of tons of the equivalent carbon dioxide emitted in base year **t.**

$Revenue_{\mathbf{t}}$ = Gross Revenue reported in standardized financial demonstrations from base year $\mathbf{t}_1$ in millions of *reais.*

This index came into force as of 2010 and represents a preparation of the market to operate in a low carbon economy, besides providing a performance indicator linked to climate changes.

4. Methodology

We selected companies that concomitantly participated in both sustainability indices of BM&FBovespa (ISE and ICO_2). Because of the rigor in the selection of companies participating in the indices, we presupposed that for being part of both, they would have a greater commitment to sustainability.

The fact that ICO_2 appeared in 2010 restricted sample size to seven companies acting in important sectors of the Brazilian economy: Braskem - Chemicals, BR Foods (BRF) - Food, Fibria – Paper and Cellulose, Klabin – Paper and Cellulose, Natura - Cosmetics, Suzano – Paper and Cellulose, and Vale - Mining.

Data were collected from these seven companies over six years, comprehending the period from 2010 to 2015. The information comprised annual and sustainability reports available in the companies' websites.

4.1. Modelo IPAT-e

As those used for the calculation of IPAT-e were extracted as follows:

Production: consumer goods (ton);

Technology: emissions (ton), water consumption (m^3), energy consumption (GJ), generation of effluents (m^3) and waste production (ton);

Afterwards, data on water consumption and generation of effluents that were expressed in m^3 (cubic meters) and energy, expressed in GJ (*Gigajoules*), were converted into tons for their representation on an equal basis.

Data were organized by company in a time series comprehending six years (2010–2015), After that, IPAT-e was calculated through the application of IPAT, as per Formula 1: I = P x A x T, where I = Impact, P = Population, A = Affluence and T = Technology.

Formula 1 was considered with adaptations for IPAT-e, resulting in Formula 2: $I = P\,x\,T$, where: I = Impact, P = Quantity Produced and T = Technology.

In light of the premise that the Technology used for production will influence Impact size, being able to increase it or reduce it, formula 1 was considered for IPAT-e with adaptations, arriving at Formula 2, as follows: $I = P\,x\,T$, where I = Impact, P = Quantity Produced and T = Technology. In this case, Impact is defined by Production x Technology (water, energy, effluents, atmospheric emissions and solid residues).

The main variable of the IPAT-e indicator formula is Production, which replaces the variables "population" and "consumption" from the original IPAT equation. This variable directly influences the others that make up the Technology item. The premise was that even if the volume produced increased, there would be less impact in case the company adopted cutting-edge technologies. To confirm this hypothesis, we evaluated the variations and elasticity of Technology variables in relation to production.

York et al. (2003) argue that although there is no single operational measure of technology that is free of controversy, it includes many factors and can be disaggregated. The technology term could be factors that affects impact per unit of production. The authors suggest the use of the STIRPAT, which is not an accounting equation, but a stochastic model that can be used for hypothesis testing. In this case a stochastic error is added to the model, which can be estimated using log transformation. The technology term can be decomposed and has multiplicative form in the usual way as it is done in the STIRPAT. The authors highlight the importance of including different factors to capture several aspects of the technology term.

Brizga et al. (2013) decompose the technology term using total value added of industry per unit of GDP, total final energy consumed to produc one unit of added value of industrial production, fossil fuel intensity and total CO2 emissions per unit of fossil fuel consumed. They use both a multiplicative and additive decomposition techniques to calculate the change in CO2 emission. After using this disaggregated specification for the IPAT identity the authors are able to address which factors have a larger impact and discuss how to reduce environmental damages in the former Soviet countries.

Li et al. (2017) suggest that technology can be disaggregated in energy intensity and emissions intensity. The former is related to the ratio of energy consumption to unit of economic output, whereas the latter to the ratio of emissions to unit of energy consumption. The disaggregation allows a better understanding of the effects of public policies to reduce pollution.

Several authors have expanded the IPAT model and include a variety of factors to proxy for technology. Magee and Devezas (2018) use a model of technological change to derive an extended version of the IPAT (IPATeK). Chontanwat (2018) also use an extended version of the IPAT decomposing the technology factor. Ma et al. (2017) also suggest that more research is warranted to include additional factors in the IPAT specification to further explore energy savings. The authors combine the IPAT with the LMDI decomposition.

In agreement with this literature, the technological factor was expanded and the multiplicative form was adopted, which allowed to estimate an extended IPAT model and to evaluate the elasticities of each factor, which allowed a better understanding of the impact of individual factors. This is useful for designing public policies aimed at improving technology and reducing environmental damage to the planet.

Equation use is based on the assertive that technology improves the productive process. Furthermore, the higher the technology level used by the company, the lower the quantity of water and energy consumption, and consequently the lower the atmospheric emission, the effluents and the solid waste generation.

After calculation of IPAT-e, we proceeded to its conversion into an index, as per Formula 3: $T = I/P$, where T = Technology, I = Impact and P = Production.

Thus, it was possible to carry out analyses of IPAT-e and verify its evolution, as well as its value to companies.

For the calculation of IPAT-e variations, we used Formula 4: $\Delta = (VF - VI)$, where:

V_F = Final value, represented by the year 2015, and
V_I = Initial value, represented by the year 2010.

Production elasticity (ε) was calculated on the basis of Formula 5: $\varepsilon = \frac{\Delta P}{Pi}$, where:

ΔP = variation in Production, calculated as per the variation formula described in Formula 4. P_i = initial Production, represented by the year 2010.

After production variations and elasticity were obtained, we calculated the elasticity of each variable that integrates the technology item in relation to production, in order to verify which variables were influenced by variations occurred in production.

At this point, we followed the formula contained in the studies of Vasconcelos (2001) to calculate elasticity, $\varepsilon_{x,y}$ being $y = (\textit{Variation \% in “y”}/\textit{Variation \% in “x”})$.

$$\text{Hence,}\ \ y = \left[\frac{\left(\frac{x1-x0}{x0}\right)}{\left(\frac{y1-y0}{y0}\right)}\right] = \left[\frac{\left(\frac{\Delta x}{x0}\right)}{\left(\frac{\Delta y}{y0}\right)}\right] = \frac{(x*yo)}{(y*x0)},$$

where ε = elasticity, x_o = initial moment, x_1 = final moment, Δ = variable difference between final and initial moment (input and output).

Doll and Orazem (1984) used the concept of input and output to explain Production Elasticity as a measure for the degree of output response to variations in the use of input. The authors clarify that production elasticity is independent of measure units. It is presented by Formula 6: $\varepsilon_p = \left(\frac{\%\ of\ input\ variation}{\%\ of\ output\ variation}\right)$.

In this way, the authors showed that it was possible to determine production elasticity, as demonstrated in Formula 7: $\varepsilon_p = \left[\left(\frac{\Delta y}{y}\right)/\left(\frac{\Delta x}{x}\right)\right] = \left[\left(\frac{x}{y}\right) * \left(\frac{\Delta y}{\Delta x}\right)\right]$

Grounded on research data, variations in production and in variables that make up the Technology item in the IPAT-e indicator formula were calculated, and subsequently so was technology elasticity in relation to production.

After verifying the influence of production on diverse variables that compose the Technology item, production was regarded as input and variables that compose the Technology item as output.

In this case, the formula adopted was the following: $\varepsilon_{production,\ technology}$:

Formula 8: $\varepsilon P = (\Delta\%\,Technology/\Delta\%\,Production)$, which is equivalent to:

$$\varepsilon P = \left\{\left[\frac{(T15 - T10)}{T10}\right]\bigg/\left[\frac{(P15 - P10)}{P10}\right]\right\} \text{ thus, } \varepsilon P = \left[\frac{\left(\frac{\Delta T}{T10}\right)}{\left(\frac{\Delta P}{P10}\right)}\right] \text{ hence, } \varepsilon P = \left(\frac{P10}{T10}\right) * \left(\frac{\Delta T}{\Delta P}\right)$$

Formula adapted from the elasticity equation of Doll and Orazem (1984).

In the calculation of IPAT-e, we used Formula 2, and then, for its transformation into a Technology index, Formula 3.

5. Results and discussion

Table 1 presents variables and values calculated for IPAT-e, based on the companies' database assessed in time series 2010–2015.

Braskem's IPAT-e made it possible to visualize the behavior of the series and variables that contributed, in each period, for the increase or reduction of the impact generated by the company. For example, in 2010, it used 6.6 tons of water for each produced unit and, by 2015, that amount declined to 4.99 per ton. The same occurred with energy, atmospheric emissions and effluents. However, the company was not efficient in reducing solid waste, which

Table 1
IPAT-e calculation by company – time series 2010 to 2015 (data per ton).

COMPANY –UNIT DATA	YEAR						
BRASKEM	2010	2011	2012	2013	2014	2015 Δ%	Δ%
PRD	12626057	11782856	13295248	13499387	12878988	13272118	+5
WC	6.60	6.86	6.88	5.25	5.18	4.99	
EC	3.15	3.59	3.50	3.37	3.56	2.51	
AE	1.22	1.66	1.68	1.64	1.69	1.19	
EF	1.24	1.32	1.18	1.46	1.59	1.15	
SW	3.05	4.84	4.06	5.22	5.16	4.49	
IPAT-e	192617792	215294111	230043613	228686359	221212719	190115351	
IPAT-e per Unit	15.26	18.27	17.30	16.94	17.18	14.32	−6
BRF	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Δ%**
PRD	16294000	17036000	17612000	16450000	14667000	14795000	−9
WC	3.76	3.66	3.48	3.99	4.07	3.94	
EC	0.40	0.38	0.50	0.64	0.67	0.64	
AE	0.06	0.21	0.25	0.27	0.27	0.24	
EF	3.26	3.27	3.17	3.39	3.81	3.68	
SW	0.03	0.03	0.03	0.03	0.03	0.02	
IPAT-e	122292481	128568148	130666347	136700264	129639704	126251609	
IPAT-e per Unit	7.51	7.55	7.42	8.31	8.84	8.53	+14
FIBRIA	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Δ%**
PRD	5542000	5277000	5299000	5259000	5300000	5185000	−6
WC	34.00	34.42	35.23	27.76	27.30	27.90	
EC	4.71	4.91	4.42	4.80	4.95	5.21	
AE	−1.56	−1.16	−0.90	−0.98	−0.81	−1.40	
EF	26.76	26.12	22.92	24.10	23.97	25.96	
SW	0.18	0.18	0.21	0.19	0.19	0.19	
IPAT-e	355173108	340247854	327945968	293819986	294639961	299981991	
IPAT-e per Unit	64.09	64.48	61.89	55.87	55.59	57.86	−10
KLABIN	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Δ%**
PRD	3393000	3445000	3988000	3533000	3510000	3570000	5
WC	20.03	19.53	17.32	17.73	17.87	17.36	
EC	1.84	1.80	1.40	1.71	1.79	1.81	
AE	0.97	0.99	0.72	0.95	1.02	1.14	
EF	15.62	15.69	13.84	15.12	16.74	16.47	
SW	0.31	0.32	0.23	0.34	0.05	0.04	
IPAT-e	131559001	132058370	133690369	126627492	131474379	131472920	
IPAT-e per Unit	38.77	38.33	33.52	35.84	37.46	36.83	−5
NATURA	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Δ%**
PRD	76721	84941	93015	112100	110776	101346	+32
WC	2.62	2.92	2.79	2.59	2.66	2.90	
EC	0.69	0.71	0.69	0.61	0.69	0.76	
AE	3.30	3.12	3.21	2.93	3.00	3.17	
EF	1.34	1.19	1.45	1.20	1.36	1.49	
SW	0.14	0.14	0.17	0.14	0.15	0.15	
IPAT-e	620699	685976	772736	837979	870586	858758	
IPAT-e per Unit	8.09	8.08	8.31	7.48	7.86	8.47	+5
SUZANO	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Δ%**
PRD	2745000	3087000	3187349	3224754	4282700	5582000	+103
WC	38.19	34.92	33.74	35.30	31.64	24.76	
EC	6.14	6.86	6.08	9.60	5.62	4.76	
AE	0.38	0.44	0.43	0.40	0.29	0.41	
EF	26.96	23.88	28.25	27.95	24.69	19.01	
SW	0.20	0.18	0.20	0.21	3.15	0.23	
IPAT-e	197298948	204618524	218953471	236903386	280039675	274456130	
IPAT-e per Unit	71.88	66.28	68.69	73.46	65.39	49.17	−32
VALE	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Δ%**
PRD	369951000	379304000	403044000	390178000	416517000	428132000	+16
WC	3.42	3.57	3.93	3.54	3.58	4.58	
EC	0.17	0.14	0.13	0.12	0.11	0.11	
AE	0.30	0.86	0.62	0.62	0.65	0.64	
EF	0.21	0.29	0.23	1.19	0.77	0.90	
SW	1.96	2.29	2.66	2.58	1.81	2.26	
IPAT-e	2244353537	2708037285	3058076291	3143228107	2879506119	3634818164	
IPAT-e per Unit	6.07	7.14	7.59	8.06	6.91	8.49	+40

Production (PRD); water consumption (WC); energy consumption (EC); atmospheric emissions (AE); effluents emission (EF); solid waste (SW). Δ% = percentage variation.
Source: elaboration of the authors.

increased in relation to the year 2010, although it reduced in the last three years. This variables performance shown by the indicator positively influenced Braskem's environmental performance, reducing its impact from 15.26 in 2010 to 14.32 per produced unit (ton) in 2015, despite the increase in production volume, that is, it increased production at 5% and reduced impact by 6%.

When analyzing the percentage variation that corresponds to the annual production behaviour of total IPAT-e and Braskem's production per unit, we find a year-on-year fall of both total and unitary environmental impacts, confirming the efficacy of contingency measures adopted by the company and making it possible that an inversely proportional variation occur in production behaviour and its respective environmental impact.

The IPAT-e index has been presenting growth for BRF. That shows signs of inefficiency in its environmental impacts mitigation measures. Possible causes of this decrease in environmental efficiency mainly stem from the increase in energy and water consumption, as well as in atmospheric emissions and effluents. The efficiency of measures was only observed in solid waste, which remained constant over five years and reduced by 0.01 per produced unit in 2015. When analyzing quantity produced, the negative performance of the company becomes more evident. That is because even when quantity produced decreased by 9%, the impact per unit (ton), on the contrary, increased by 14%. Annually, BRF's environmental impact fell unitarily, but absolute amount increased. This evidences the ineffectiveness of some contingency measures adopted by the company.

Fibria's IPAT-e showed a decreasing behaviour, evidencing that the company became efficient in its environmental impacts containment measures. It was particularly efficient in atmospheric emissions containment, which was compensated with positive balance since 2010. Water consumption drop from 34 to 27.9 and effluents emission also presented reduction as of 2010, despite having reached the minimum of 22.92 in 2012 and having increased until 2015. As for solid waste, they remained practically unchanged.

Fibria's inefficiency lies in the energy consumption item. Although it had reached a minimum of 4.42 in 2012, it rose up to 5.21 in 2015, resulting in the loss of the company's efficiency in its time series and affecting IPAT-e. In the 2010 time series, production was 5 million tons. With an impact of 64.09 per ton, it fell an average of 57.86 per unit in 2015, a fall of 10% resulted not only from the reduction of 6% in production volume, but mainly from the improvement of its capability to minimize environmental impacts per unit (ton). Total and unitary environmental impact of Fibria were inversely proportional to production behavior.

Contingency measures presented the highest efficacy. However, when analyzing years 2014–2015, there is a change in this behaviour, with fall in production percentage, but increase in total and unitary environmental impact.

Klabin's IPAT-e index was 38.77 in 2010, reached at least 33.52 in 2012 and oscillated until 2015, still maintaining an efficiency gain sustained by the reduction in water consumption and solid waste generation. Despite the reduction of atmospheric emissions in 2012, an increase from this year until 2015 occurred, surpassing the 2010 mark. The company shall also observe more carefully effluents emission levels. Overall, the index performance was positive, since even when the produced volume increased by 5%, the environmental impact per produced unit (ton) reduced by 5%.

With regard to Natura's IPAT-e, it is possible to visualize that the indices in the time series did not present great oscillations nor showed great improvements. Compared to 2010, the company was inefficient in 2015 for the parameters of water consumption, energy, effluents and solid waste generation. Only atmospheric emissions stood out in a positive way in relation to the year 2010. When analyzing unitary indices, we note that the indicator increased by 5%, from 8.09 to 8.47. At the same time, production went up to 32%, which suggests some decisions and proactive actions for the improvement of its environmental performance.

As for Suzano, the indicator showed exceptional environmental performance since 2010, insofar as it gradually reduced its impacts with expressive gains in water and energy consumption and in the reduction of effluent emissions. Atmospheric emissions performance was not a highlight, as they increased since 2010. This environmental efficiency becomes even more evident when compared to the expressive increase in quantity produced (103%) and in the impact per unit (ton) reduction at 32%. Suzano's annual impact fell from 2013 onwards and it was inversely proportional to production increase, confirming the effectiveness of contingency measures effectively implemented.

With regard to the Vale Company, the indicator has been growing since 2010, indicating inefficiency in its environmental impacts mitigation measures. Negative highlights are water consumption, atmospheric emissions, effluents and solid waste. Gains are only relevant in energy consumption reduction. It is worth emphasizing that an IPAT-e score increase for the Vale Company represents a much increased environmental impact, because of the company's significant production volume. The negative performance stands out when comparing the rise in production volume at 16% and the impact increase of approximately 40%.

The Vale Company causes great impact, and even in view of a significant volume of environmental investments and all implemented measures, its impact rises proportionally with production, in such a way that in the last observed year this increase was even higher. Hence, the company produced more with greater impact and with solid waste accumulation representing one of the main causes of this imbalance.

5.1. Production elasticity analysis

The IPAT-e value is an additional information produced by a variant of the original IPAT equation. Chertow (2008) argues that it is necessary to go further and apply statistical, mathematical and econometric tools to validate the model. Such procedures were part of the works of Raven (2012), Stewart (2014) and mainly Dietz and Rosa (1994), who applied econometric models and therewith created STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology). In this regard, data analysis showed the need to calculate variations intensity. This was possible through the calculation of Elasticity, which revealed the impact size that an alteration within a variable exerts on another in percentage terms (Vasconcelos, 2001). We considered alterations in water and energy consumption, atmospheric emissions, effluents and solid waste in their relation with changes occurred in production.

Results obtained show the following particularities:

a) When technology elasticity is greater than 1 ($T > 1$), the variable is sensitive to production elasticity and production growth influences it;
b) When technology elasticity is smaller than 1 ($T < 1$), it indicates that the variable is little sensitive to production elasticity, that is, it will not suffer influences as changes occur in production;
c) When technology elasticity equals 1.0 ($T = 1.0$), unitary elasticity occurs.

The application of elasticity to measure companies' environmental performance has been widely disseminated. An example is the economic growth effect on investments made by industrial companies to prevent pollution, concluding that elasticity is positive when there are public policies that encourage such investments (Yong-Chao and Zheng-Juan, 2017).

When replacing the formulas of Production elasticity (Formula 5) and items part of the Technology element (Formula 7) described in methodology by research data, we have the results presented in Table 2.

Braskem's production elasticity showed that each additional unit produced represented 0.05 of increase in its production. In the analyzed period, however, only solid waste was sensitive to this rise. The other variables showed little or no sensitivity to the increase, a fact that contributed to the improvement of the company's IPAT-e during the period.

With regard to BRF, elasticity of production was −0.09 for each unit additionally produced. Even with reduction in production, there was no decrease in water and energy consumption, in atmospheric emissions and effluents, which reveals that they are little sensitive to production elasticity. Only solid waste was sensitive to production elasticity, accompanying its behaviour. This may indicate that the company was not so efficient in the environmental sustainability issue, which the IPAT-e rise confirms.

The Fibria Company had a falling production volume in the analyzed period. Water consumption accompanied the production trend, being sensitive to that reduction just as industrial effluents, revealing the company's efficiency in the two variables, mainly due to fact that they have greater weight in the IPAT-e composition. Atmospheric emissions also responded to production decrease, to which the variables of energy consumption, effluents and solid waste were not sensitive.

Klabin presented rise in its produced volume during the analyzed period. Atmospheric emissions and effluents generation responded to that increase, aspects to which the company should give special attention. Water and energy consumption, as well as solid residues generation did not respond to that increase. In this context, water consumption is a highlight aspect, for it represents the item of greatest weight in the company's IPAT-e and, despite increase in production, water did not present any sensitivity, representing a positive and desirable aspect for the company.

With regard to Natura, production went up during the period. Moreover, it revealed good environmental performance, since none of the variables contained in IPAT-e presented great sensitivity to that increase. However, the index still presented growth, observed in the overall context where only atmospheric emissions showed significant reduction in the face of the rise in production.

Suzano increased its production from 2010 to 2015. None of the variables that compose IPAT-e were sensitive to that rise, evidencing efficiency in terms of environmental sustainability. That highlights its significant efficiency in actions to reduce its impact size.

Vale's production increased and water consumption, atmospheric emissions and effluents generation were sensitive to that rise in a much greater proportion than values observed for production. That reveals a fall in its impacts containment efficiency. Only water consumption and solid waste were not sensitive to that increase.

When assessing the elasticity behaviour with focus on variables that compose IPAT-e, the effort of some companies in the sense of reducing their impacts size and consequently improving future results is noticeable. That ties in with the assertive that environmental management relates positively to financial performance in subsequent years, implying better future profitability performance (Song et al., 2017).

Table 2
Production/technology elasticity and their components by company - series 2010 to 2015 (data expressed in tons).

Unit data	Year			
Braskem	**2010**	**2015**	**Variation**	**Elasticity**
PDR	12626057	13272118	646061	0.05
WC	6.60	4.99	−1.61	−4.77
EC	3.15	2.51	−0.64	−3.97
AE	1.22	1.19	−0.03	−0.52
EF	1.24	1.15	−0.09	−1.42
SW	3.05	4.49	1.44	9.25
IPAT-e	192617792	190115351	−2502441	
IPAT-e per Unit	15.26	14.32	−0.93	
BRF	**2010**	**2015**	**Variation**	**Elasticity**
PDR	16294000	14795000	−1499000	−0.09
WC	3.76	3.94	0.19	−0.54
EC	0.40	0.64	0.24	−6.54
AE	0.06	0.24	0.19	−35.02
EF	3.26	3.68	0.42	−1.41
SW	0.03	0.02	−0.01	2.72
IPAT-e	122292481	126251609	3959128	
IPAT-e per Unit	7.51	8.53	1.03	
Fibria	**2010**	**2015**	**Variation**	**Elasticity**
PDR	5542000	5185000	−357000	−0.06
WC	34.00	27.90	−6.10	2.79
EC	4.71	5.21	0.50	−1.65
AE	−1.56	−1.40	0.16	1.59
EF	26.76	25.96	−0.80	0.47
SW	0,18	0,19	0,01	−1,24
IPAT-e	355173108	299981991	−55191118	
IPAT-e per Unit	64.09	57.86	−6.23	
Klabin	**2010**	**2015**	**Variation**	**Elasticity**
PDR	3393000	3570000	177000	0.05
WC	20.03	17.36	−2.67	−2.56
EC	1.84	1.81	−0.03	−0.31
AE	0.97	1.14	0.17	3.40
EF	15.62	16.47	0.85	1.04
SW	0.31	0.04	−0.27	−16.61
IPAT-e	131559001	131472920	−86081	
IPAT-e per Unit	38.77	36.83	−1.95	
Natura	**2010**	**2015**	**Variation**	**Elasticity**
PDR	76721	101346	24625	0.32
WC	2.62	2.90	0.28	0.33
EC	0.69	0.76	0.08	0.35
AE	3.30	3.17	−0.13	−0.12
EF	1.34	1.49	0.15	0.35
SW	0.14	0.15	0.01	0.18
IPAT-e	620699	858758	238059	
IPAT-e per Unit	8.09	8.47	0.38	
Suzano	**2010**	**2015**	**Variation**	**Elasticity**
PDR	2745000	5582000	2837000	1.03
WC	38.19	24.76	−13.43	−0.34
EC	6.14	4.76	−1.39	−0.22
AE	0.38	0.41	0.02	0.06
EF	26.96	19.01	−7.95	−0.29
SW	0.20	0.23	0.03	0.14
IPAT-e	197298948	274456130	77157182	
IPAT-e per Unit	71.88	49.17	−22.71	
Vale	**2010**	**2015**	**Variation**	**Elasticity**
PDR	369951000	428132000	58181000	0.16
WC	3.42	4.58	1.15	2.14
EC	0.17	0.11	−0.06	−2.20
AE	0.30	0.64	0.34	7.21
EF	0.21	0.90	0.70	21.51
SW	1.96	2.26	0.29	0.95
IPAT-e	2244353537	3634818164	1390464627	
IPAT-e per Unit	6.07	8.49	2.42	

Production (PRD); water consumption (WC); energy consumption (EC); atmospheric emissions (AE).
Effluents (EF); solid waste (SW).
Source: elaboration of the authors.

6. Conclusions

After considering the assessed companies that compose both indices of BM&FBovespa (ISE and ICO_2) and applying IPAT-e, we conclude:

i) The indicator showed efficacy in assessing production technological efficiency, allowing to identify which variables cause impact over a period of time;
ii) Paper and cellulose companies are those that most impact. On the other hand, they stand out in the improvement of productive efficiency aligned with the pursuit of sustainability. Efficient mitigation actions in the face of pollutant emissions evidence this aspect.
iii) There is no direct relation between variation in quantity produced and impact size, for the technology variable is what influences impact generation, that is, production elasticity may influence or not variables that cause impact, depending on the degree of technology adopted by the company.

The research contributes to broaden the literature concerning corporate environmental sustainability indicators, since it presents a new variant for the IPAT equation.

The information obtained may subsidize stock exchanges, especially BM&FBovespa (Brazil), making ISE and ICO_2 more efficient, as well as providing information that will contribute to investors' decision-making on directing resources to companies with the best environmental sustainability performance, for it allows accompanying impact size over the years.

Another contribution from IPAT-e is the possibility of subsidizing governmental organisms in the formulation of environmental public policies associated with the companies' performance, as well as evaluating the efficacy of performed environmental investments. We highlight that when considering businesses models integrated to sustainability, it becomes possible to involve small and medium companies as an object of analysis.

The fact that the two indices (ISE and ICO_2) had been concomitantly used restricted sample size to seven companies, which can be seen as a limiting factor. However, the inclusion of companies into the two sustainability indices is dynamic, and sample limitations in the present study can be overcome in future researches, in which other companies with more diversified activities could be considered for environmental performance analysis through IPATe, meeting its requirements.

As with IPAT, components of the technology item are variable. In the IPAT-e, it is also possible to consider other components that impact the environment and may stem from economic activities explored by the companies selected in the research, constituting one more option for future studies involving the indicator, which is not only restricted to elements considered in the present research.

Moreover, it is suggested that analyses be carried out with the application of IPAT-e in companies from different sizes, sectors and countries, aiming to compare them and to investigate how economies and their public policies are impacting the environment.

Conflicts of interest

The authors declare no conflict of interest.

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