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The Representation of Graphene in the Online Press of the United States, the United Kingdom, and Spain

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Graphene is the first two-dimensional material discovered by humans. It was isolated for the first time in 2004 and is being established as a revolutionary material for the 21st century. This study presents an analysis of the quantitative and qualitative contents from all news about graphene published online in *The New York Times* (United States), *The Guardian* (United Kingdom), and *El País* (Spain) from October 2004 to October 2017. We evaluate the media's coverage of a new, revolutionary material such as graphene in terms of the volume of news items per year and the authorship and treatment, thematic focus, and content of the articles—from both a quantitative and a qualitative perspective. This analysis offers insights into the knowledge transfer about graphene and can serve as a model to the materials science communication field.

Keywords: graphene, science and the media, science communication, popularization of science and technology, representations of science and technology, communication of graphene, online press analysis

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The first isolation of graphene in 2004 and its implications changed the paradigm established by the laws of physics and opened the door to new, previously unheard of industrial applications (Ferrari et al., 2015). Numerous advances in research and industry have followed this discovery, and the mass media industry has been responsible for communicating these advances to broader audiences.

Despite the hundreds of mass media content studies in recent decades (Eveland & Cooper, 2013), none have examined news articles about graphene, probably because the material is still in the early stages of development. Our content analysis of online media shows how scientific information about graphene is presented to the public and, thus, which aspects are most covered over time by representative media organizations in three countries that are pioneers in the graphene field (ComScore, 2018; Nixon, 2015).

The study consists of a quantitative and qualitative content analysis of all articles about graphene published by leading digital media organizations in three important Western countries for manufacturing and research on graphene. They are *The New York Times* (the United States), *The Guardian* (the United Kingdom), and *El País* (Spain).[1] The study includes news items published between October 2004 and October 2017, a total of 13 years.

Context

Graphene and the Media

Graphene is the most important two-dimensional material discovered to date.[2] It was first isolated in 2004 at the University of Manchester, and according to the European Parliament, it is one of 10 technologies that could change our lives (Van Woensel & Archer, 2015). It is not surprising, then, that the material has captured the interest of the scientific community, industry, and governments on a global scale. This interest can be quantified in several ways, such as companies' dedication to graphene research, the development of new applications for the market, and the interest in publishing and communicating the advances of the material. Furthermore, it appears that graphene will replace certain existing technologies and materials, including silicon in applications such as photovoltaic plates and microchips (Novoselov et al., 2012).

Indeed, graphene and other synthetic carbon allotropes are currently at the forefront of materials science and nanotechnology. Expectations about the many practical applications of these materials are seen not only among the scientific community but also the public, leading companies, and politicians around the world (Hirsch, 2015). As with many issues that are not readily visible to the public, the media are used as

[1] The articles in *El País* were translated into English by experts before performing the content analysis.

[2] Graphene is a single layer of carbon atoms that are bonded together. Notable among its unique properties are its resistance, transparency, flexibility, impermeability, and hardness. It is also the thinnest material in the world, at 0.34 nanometers. It is currently the best known conductor of electricity and heat, and it is also an isotropic conductor. Chemically, it is an inert material that can absorb different atoms and molecules. It is impermeable to gases and can be functionalized by various chemical groups (Mertens, 2015).

a vehicle to inform society about graphene production networks and the potential they represent for industry (Dudo & Besley, 2016).

Due to the complexity of the subject of graphene and the difficulties associated with communicating this complexity, the media must continuously adapt highly technical knowledge into clear and accessible language for the public (Kueffer & Larson, 2014). Once people are out of formal schooling, mass media content is the primary source for scientific information (National Science Board, 2012). Therefore, the media act as "scientific gatekeepers" between research findings published in the scientific community and nonscientists (Eveland & Cooper, 2013; Shoemaker & Vos, 2009). The media thus are empowered to decide what pieces of information are most relevant to be published and disseminated.

Gatekeeping is, in fact, one of the media's main roles. People trust journalists to inform them about relevant advances, which means that journalists need to review a great amount of information to select the events and developments that are remarkable enough to be part of the manageable amount of information that they disseminate to the public (Shoemaker & Vos, 2009). Moreover, the coverage of a scientific topic varies depending on the medium, the news source, and over time (Eveland & Cooper, 2013).

Media coverage of any given topic occurs through a process called agenda setting—by continuously giving citizens cues about the importance of an issue, over time the media's agenda conditions the public agenda to a large extent (McCombs, 2004). In other words, the issues that the media emphasize are the ones that society comes to perceive as most relevant. Researchers such as Meraz (2011) argue that this process continues to operate in the digital age, which is crucial, considering that audiences increasingly turn to online sources. About seven in 10 Internet users go online to search for information about scientific issues, recent findings, definitions of scientific terms, and answers to questions about scientific concepts (Horrigan, 2006).

The process carried out by media organizations to convey information about scientific advances is called science communication. This process has been defined by several authors (Bell, Lewenstein, Shouse, & Feder, 2009; Burns, O'Connor, & Stocklmeyer, 2003; Fischhoff & Scheufele, 2013; Jucan & Jucan, 2014). Any science communication process involves knowledge transfer—the flow of information about scientific advances between researchers and society (Johnson, 2005). Researchers generate this knowledge, and disseminators reformulate the scientific discourse to make it more accessible to wider audiences (Cortiñas Rovira, 2008; Johnson, 2005). News agencies select which topics to disseminate (Boumans, Trilling, Vliegenthart, & Boomgaarden, 2018).

As a society, we rely on the scientific information that journalists publish as the basis for forming opinions and making decisions. The online ecosystem has dramatically altered the way individuals find information about science and follow scientific findings and developments (Brossard, 2013). The Internet has become the primary source (59%) for people seeking information about science and technology topics (Günther & Domahidi, 2017)—a trend that has increased steadily since 2001 (National Science Board, 2014). There is an evident inclination toward online sources for science-related—and thus nanotechnology- and

graphene-related—information as well as an interest in learning about scientific subjects in greater depth (Anderson, Brossard, & Scheufele, 2010).

This change from print to online media has entailed many structural changes in journalism organizations. To manage the transition successfully, organizations have transferred much of their content to digital platforms (Bechmann, 2012). Content from traditional journalism organizations dominates the online information repertoire thanks to the public's familiarity and strong links with these organizations (Wolf & Schnauber, 2015).

Stakeholders and Language

Graphene is increasingly arousing the interest of governments and companies operating in multiple market sectors. Many governments and large corporations have announced graphene research and development projects (Ghavanini, 2015; Intellectual Property Office, 2015). For instance, the European Commission has allocated €1 billion for graphene research in Europe. Along with the Human Brain Project, it is the most important research initiative ever undertaken in Europe (Hirsch, 2015). The main goal of the project is to bring together academic and industrial researchers to take graphene from laboratories into society (Graphene Flagship, 2015).

Since the institutions interested in graphene—governments, companies, and the scientific community—come from various disciplines, the communication of science should be regarded not as a simplification of contents but as a recontextualization of the scientific discourse to a different domain in order to achieve a particular purpose (Luzón, 2013). Generally, cultural orientations (Medin & Bang, 2014) and resources such as metaphors (Boeynaems, Burgers, Konijn, & Steen, 2017; Kueffer & Larson, 2014) help transform this discourse into something understandable to readers in other fields of study and improve the quality of science communication (Medin & Bang, 2014). Indeed, achieving quality in knowledge transmission is one of the greatest challenges involved in communicating science topics to the public. Bucchi (2013) asserts that science should move from its "heroic phase"—distanced from society—to a phase in which quality is the priority for all parties involved.

Objective

Our main purpose is to analyze how *The New York Times*, *The Guardian*, and *El País* transferred knowledge and advances of graphene from the scientific community to lay audiences over the 13 years since the first isolation of the material. The study includes the evolution over time in news coverage of graphene in terms of (a) volume of news items published, (b) authorship and treatment, (c) thematic focus and content, and (d) qualitative aspects. We assigned a research question to each of these areas of inquiry.

Our first question aims at quantifying the total number of news stories published in each media source and forming a yearly distribution over time. This distribution will permit us to discover whether there is a relationship between the number of articles published each year and the milestones around the graphene phenomenon—for example, discovery, Nobel Prize, and Graphene Flagship launch.

RQ1: What is the frequency of publication of news about graphene in each analyzed medium? Are the peaks in publication related to any social, political, governmental, or economic issue?

We also investigate the origin or source of the items analyzed as well as the treatment that is given to each story.

RQ2: Are graphene news stories mainly published by journalists or by other sources? What treatment is typically given to these stories?

A third goal is to detect the main thematic focus of the news items involving graphene. To do so, we study the main subtopics that are discussed and the geographic focus of the stories. We also analyze which market sectors are referred to most as well as which specific properties of the material seem to be most interesting from a journalistic perspective.

RQ3: *What are the main topics, countries, continents, properties, and sectors covered in the graphene-focused articles?*

Various studies have shown that most media coverage of nanotechnology has an optimistic slant toward the advantages of new materials, paying little attention to aspects such as toxicity and sustainability (Lewenstein, Gorss, & Radin, 2005; Petersen, Anderson, Allan, & Wilkinson, 2009). To explore this tendency in news stories about graphene, we conduct a qualitative assessment of the tone of the discourse and the literary devices used.

RQ4: Is the news coverage of graphene overly positive, or are the negative implications of the material also reported? What kind of language is used?

Methods

Scope

This study focuses on three important Western nations for graphene manufacturing and research: the United States, the United Kingdom, and Spain.[3] A prominent digital daily newspaper was selected from each of these three countries to carry out the analysis. In the United States, we chose *The New York Times* (NYT); in the UK, *The Guardian* (TG); and in Spain, *El País* (EP). These newspapers were selected because of their long-standing journalistic tradition and prestige, their clearly global scope, and because the audience for the online version is among the largest in each country (ComScore, 2018). For

[3] The world leaders in graphene production are the United States (24%), China (17%), India (11%), the United Kingdom (11%), Spain (10%), and Turkey (6%). These countries are followed by Canada, Italy, Japan, Netherlands, Germany, Malaysia, Norway, Poland, South Korea, Sri Lanka, and Sweden, with less than 5% each (Nixon, 2015). In terms of the percentage of resources dedicated to graphene research and development, the United Kingdom (21%), Spain (20%), China (18%), and the United States (16%) lead the research effort worldwide (Phantoms Foundation, 2015).

NYT, we also included its section *The Science Times*, because in recent years most articles about scientific topics are published there. For EP, translation experts translated all the articles from Spanish to English so that all the news items for our analysis were in the same language.

We opted to conduct both quantitative and qualitative content analyses for our methodology—a systematic and replicable analysis of a body of communicated material through classification, tabulation, and evaluation (Altheide, 1996; Krippendorff, 2004; Neuendorf, 2002). The period analyzed begins in October 2004—coinciding with the month in which the article about the first isolation of graphene was published (Novoselov et al., 2004)—and ends in October 2017.

We set out to analyze all the news stories, reports, and articles about graphene that were published by the three newspapers. The sampling process was designed to capture articles in the online versions of the three newspapers whose main topic was graphene. To select a representative sample of the coverage of the topic, we included news items that devoted 50% or more of the text to a discussion of graphene. Articles that mentioned graphene at some point but where graphene was not the focus—discussed in less than 50% of the text—were excluded from the sample (Pedhazur & Pedhazur-Schmelkin, 1991). This sampling process eliminated false positives—that is, news stories that contained tangential graphene-related content (Dudo, Dunwoody, & Scheufele, 2011). The unit of analysis was the individual news story.

In total, 82 news items included the word *graphene* in NYT, 197 in TG, and 114 in EP. We set aside the nonstory pieces such as listings, videos, and quizzes and stories in which graphene was not the central theme. After the selection process, 19 news items were selected from NYT, 22 from TG, and 26 from EP—67 pieces of information in total.

Analysis Form Description and Procedure

To carry out the content analysis, we developed an analysis form with the following fields: (a) amount of coverage, (b) authorship and treatment, (c) thematic focus and content, and (d) qualitative aspects (see Table 1). These fields directly correspond to the research questions in our study: (a) to RQ1, (b) to RQ2, (c) to RQ3, and (d) to RQ4. The categories examined within these four fields were created based on the story analysis form by Lynch and Peer (2002) and the descriptive and thematic analysis of journalistic coverage of nanotechnology by Dudo et al. (2011). The rationale for choosing these two models is that Lynch and Peer (2002) offer an exhaustive and systematic analysis—which we found appropriate for our study—and Dudo et al. (2011) offer a different perspective based on four research questions that are similar to ours.

Table 1. Analysis Form Designed for the Representation of Graphene in* The New York Times*,* The Guardian*, and* El País*.

Field	RQ	Category	Variables
(a) Amount of coverage	1	Newspaper	*New York Times*; *The Guardian*; *El País*
		Year	2004; 2005; 2006; 2007; 2008; 2009; 2010; 2011; 2012; 2013; 2014; 2015; 2016; 2017
(b) Authorship and treatment	2	Origin/source	Staff (stories coming from the newspaper); wire/news service (stories from other news services); external (from a company, laboratory, university, or technological center); reader (editorial content or letters)
		Treatment	General news; feature; commentary/criticism; interview; other
(c) Thematic focus and content	3	Subtopics (%)	Discovery; research/funding; material's features; applications
		Geographic focus	International; domestic; state/regional; none
		Countries and continents mentioned	All countries and continents
		Properties mentioned	All properties considered
		Sectors mentioned	All sectors considered
(d) Qualitative aspects	4	Tone of the discourse	Positive (focus on the advantages of graphene); balanced (both positive and negative views discussed); negative (focus on the disadvantages); critical (subjective judgements given); none
		Negative aspects	All the negative aspects considered
		Literary devices	All literary devices considered

The (a) field contains the newspaper in which the news item was published and the year of publication. Each newspaper was given a code: NYT for *The New York Times*, TG for *The Guardian*, and EP for *El País*. The variables for the year category include all years from 2004 to 2017. The (b) field consists of the origin/source and the treatment categories. Origin/source refers to the occupation of the writer of the story, and treatment refers to the type and approach of the piece of information.

The (c) field contains the subtopics that were mentioned the most. These were evaluated in percentages according to the amount of text devoted to each subtopic. The variables for this category were generated after a first reading of the articles, which enabled us to detect the top four subtopics. We also assessed the geographic focus as well as the countries and continents and properties and market sectors

mentioned. For the properties and sectors analysis, we did not determine a list of variables. Instead, we collected all the properties and sectors mentioned and worked with them afterward. Because there was a vast quantity of market sectors, we grouped them into general sectors to obtain a broader view of the global interests of industry. If one article mentioned three specific sectors within one general sector, we recorded three references.

Finally, the (d) field comprises three categories. First, the tone of the discourse evaluates whether the news stories emphasized the positive or negative aspects of graphene. Then, the negative aspects category captures the negative information discussed in the news items. Finally, the detection of the literary devices explores the various forms of expression used in the articles to describe graphene and its properties.

An assessment of intercoder reliability was conducted (Hoffman, 2006; Krippendorff, 2004; Lombard, Snyder-Duch, & Bracken, 2002). Two coders examined the articles separately with the same analysis form (see Table 1). After all the items were evaluated, the results were compared. If the information written in a category matched, that information was deemed correct. If the information was similar, the two coders discussed which result or categorization was most accurate and reached a consensus. If the information was different or if the coders could not reach a consensus, a third analyst helped decide which information should be deemed the most valid.

Results

(a) Amount of Coverage

To answer the first research question, about the number of articles appearing in the three newspapers over time, 2013, 2014, and 2017 are the years with the most news stories—14, 12, and 12, respectively (see Figure 1a). The first three years (2007, 2008, and 2009) saw only two articles about graphene—one in 2007 and the other in 2009—both in NYT. In 2010, coverage begins to increase, but not at a steady pace or in a balanced proportion among the three newspapers.

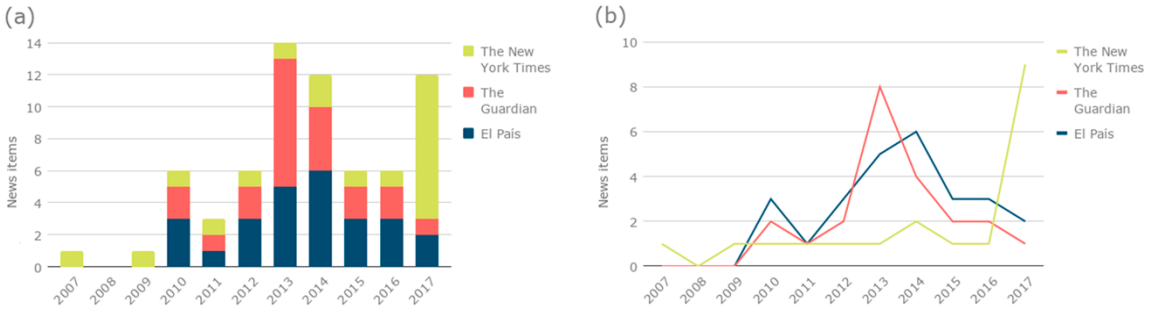

Figure 1. Distribution of the number of news articles per year (a) in a stacked bar graph and (b) for each newspaper separately.

EP and TG follow similar trends, with an initial peak in 2010 and higher peaks in 2013 and 2014 (see Figure 1b). In TG, the second peak in 2013–2014 is more sudden, while it is more gradual with EP.

The number of articles in NYT was quite constant—and much lower than in the other two newspapers. The exception is during the last year (2017), when the number of articles increased exponentially in NYT—from one or two articles per year to nine. The relationship between publication peaks and other social, economic, and political issues is discussed later in the article.

(b) Authorship and Treatment

Most of the articles about graphene in the three newspapers were written by the newspapers' own staff: 77% of EP's, 68% of TG's, and 100% of NYT's news stories were their own. The other stories were distributed evenly among external sources, other news services, and readers. The treatment of the topic tended to be generic. EP published 16 general news articles, five in-depth articles, three opinion articles, and two interviews. TG published nine general articles, eight in-depth articles, four opinion articles, and one classified as other. NYT had only two opinion articles; the rest (19) were general news stories.

(c) Thematic Focus and Content

There was a correlation among the subtopics of the stories by the three newspapers (see Figure 2a). Between 40% and 46% of the text in the stories was devoted to research and funding. The second most mentioned subtopic was the development of applications and the potential of graphene—between 28% and 31%. The third-ranked subtopic (between 19% and 26%) was on the material itself—its features, properties, and production methods. The final area of focus was the discovery of the material and the Nobel Prize—less than 8%. The main subtopic, research and funding, received the most coverage in all years except 2009 and 2010 (see Figure 2b). In 2009, the material's production and features predominated, and in 2010, the discovery was the most discussed theme. The other subtopics remained fairly constant over the years, except for 2010, when the discovery and the Nobel Prize subtopics received the most attention.

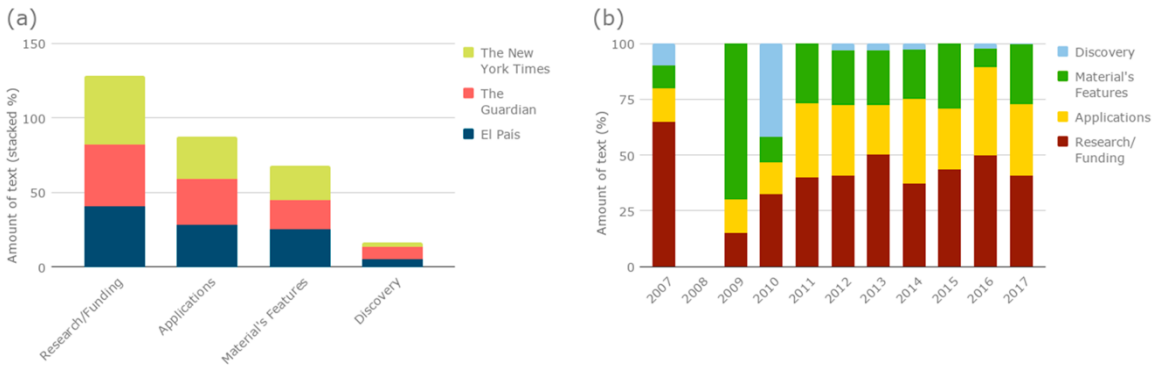

Figure 2. Distribution of the articles based on the four subtopics (a) in a stacked bar graph and (b) in percentages by year.

The geographic focus of the analyzed stories was mostly international followed by domestic—with respect to each country (see Figure 3a). EP coverage was evenly split in its international and domestic focus, with 11 articles each. By comparison, TG had nine articles with a domestic focus, eight with an international

focus, and five stories with a regional focus. In contrast to these two distributions, NYT had a stronger international focus (with 12 articles) than domestic (seven stories). Overall, the international focus was more pronounced in the first years; in 2010 and from 2012, the domestic focus became more significant (see Figure 3b).

Of the countries and continents mentioned in the articles, the United Kingdom and the United States appear most, with 37 and 30 items, respectively (see Figure 3c). Spain (19) and Europe (18) stand out next, followed by China (10) and other European, Asian, and American countries. The country each newspaper refers to the most is the paper's home country. Thus, EP mentions Spain most, followed by Europe, the United Kingdom, and the United States. TG mostly mentions the United Kingdom, followed by the United States and Europe. NYT mentions the United States most, followed by the United Kingdom. Other countries and continents are referred to much less, though it is interesting to note that European countries are mentioned much more than Asian countries, which, in turn, are referred to much more than other countries in the Americas. No country in Africa or Oceania is mentioned.

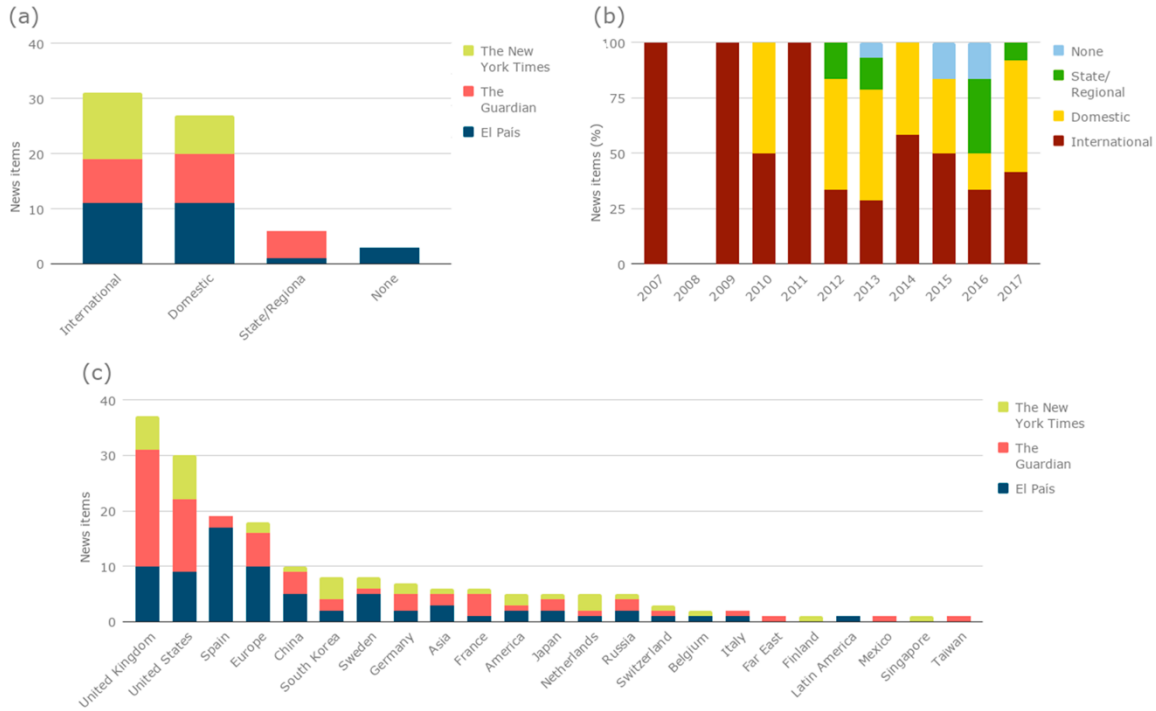

Figure 3. Distribution of the articles based on their geographic focus (a) in a stacked bar graph, (b) in percentages by year, and (c) countries mentioned.

The properties of graphene that are mentioned the most are resistance, in 37 articles, followed by electrical conductivity, in 35 (see Figure 4). The thickness of the material and its flat configuration and hexagonal matrix were the two features mentioned next, found in 30 and 28 articles, respectively. The material's transparency (19), flexibility (17), and lightness (13) were also relevant, followed by thermal

conductivity (12) and quantum-scale characteristics (10). Other properties, such as resistance to chemical agents, electronic properties, light absorption, and physical properties, are named in some stories. These are followed by hardness and impermeability. Many other properties are also named, but only between one and four times in all articles. To a large extent, the three newspapers coincide in this distribution equally, with only slight variation.

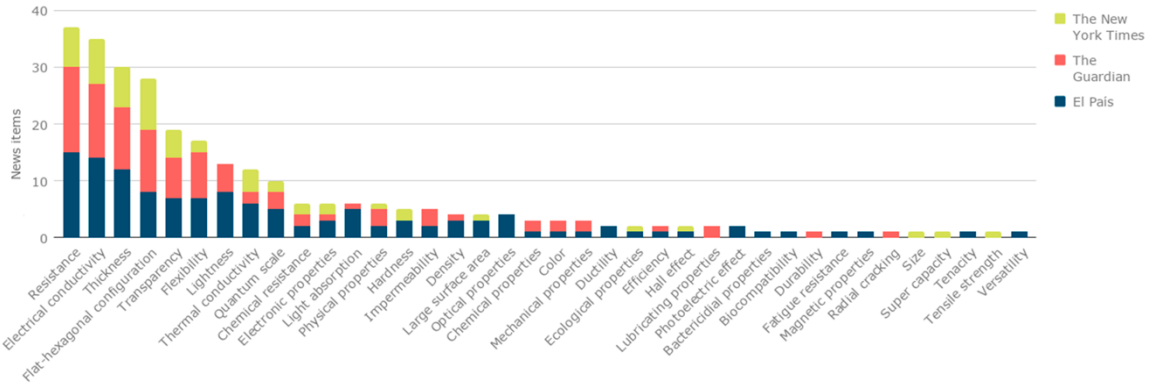

Figure 4. Properties and characteristics of graphene mentioned in the articles.

The most mentioned graphene application sectors are electronics and devices, mentioned 74 and 73 times, respectively, in the three newspapers (see Figure 5). Electronics and devices are separate categories because there were many references to each, and most articles made this distinction. Other noteworthy fields mentioned, albeit less often, include transport (30), the environment (27), everyday applications (26), and medicine (25), followed by biological, chemical, and sensory applications (20). To a lesser extent, applications are also mentioned for material science, manufacturing, and condoms. Separating the results by newspaper, EP mentions devices most, followed by electronics and applications in sensors and biochemistry. Electronics predominates in TG stories, followed by devices and transportation. Finally, NYT focuses equally on electronics and devices, with all other fields discussed much less often.

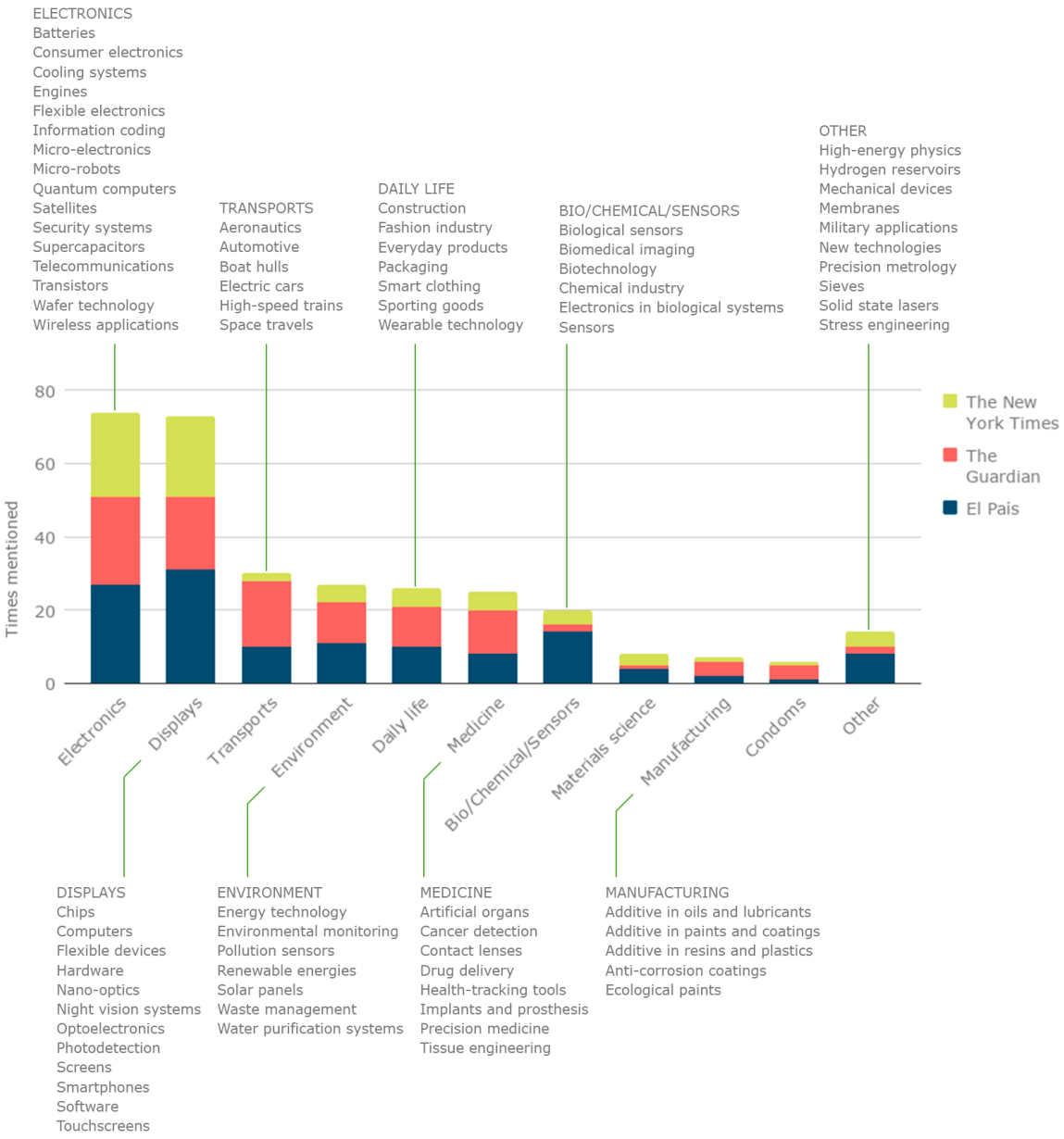

Figure 5. Market sectors cited in the news items, including the specific and general sectors mentioned for the application of graphene.

A clear relationship exists between graphene's properties and the sectors of greatest interest. Resistance and electrical conductivity are favorable properties for the development of electronic components and devices. This relationship is discussed later in the article.

(d) Qualitative Aspects

In our qualitative assessment of the news, we found that 66% of the articles conveyed a positive tone (see Figure 6a). EP and NYT display a marked trend in this sense, with 19 and 16 positive stories, respectively. In contrast, TG has about the same number of articles with a positive tone (nine) as a balanced one (eight), and five stories with a critical tone. A negative tone is not predominant in any of the articles. We detected an evolution in the tone over time (see Figure 6b). A positive approach dominated early coverage; in 2011, most articles had a balanced tone; and as of 2013, the first publications with a critical or neutral tone appeared.

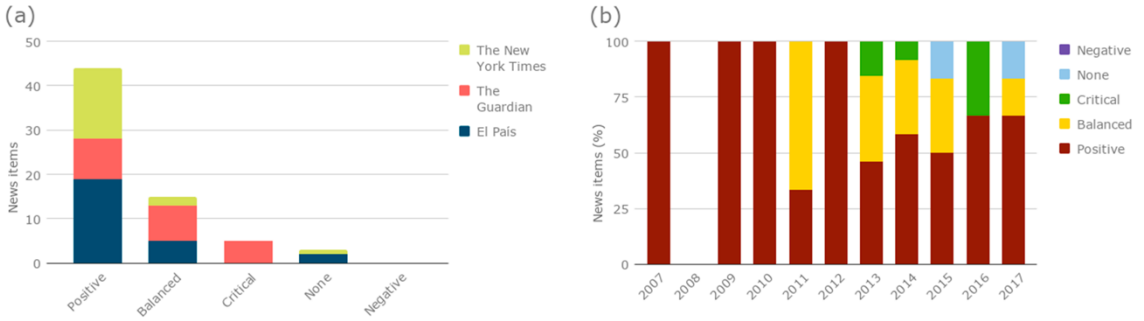

Figure 6. Distribution of the articles based on the general tone of the discourse (a) in a stacked bar graph and (b) in percentages by year.

In balanced and critical news, the disadvantages of graphene are discussed mainly in terms of scalability of production (11 articles) and economic factors (nine stories; see Figure 7). Time and the material's quality are also critical factors, with seven and six articles, respectively, followed by production and marketing, with five stories each. Finally, possible toxicity and environmental repercussions, certain properties of the material, and the lack of regulation were also mentioned.

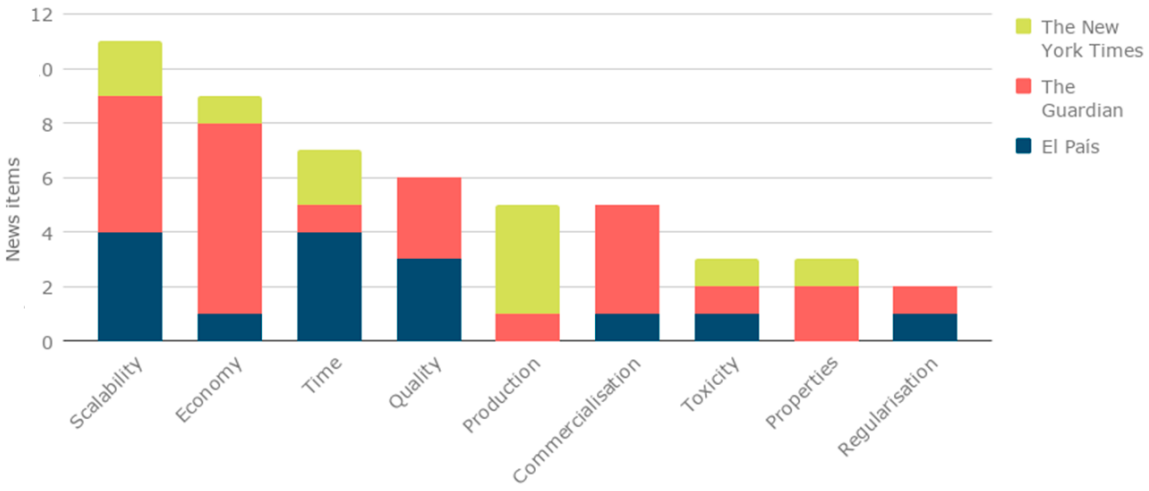

Figure 7. Quantification of the negative aspects of graphene mentioned in the articles.

Looking at the language the newspapers used to explain graphene, all but three of the 67 articles employed literary devices to achieve a stylistic effect in the text. The most commonly used devices are quotes and comparisons, followed by hyperbole, speculative language, and metaphors (see Figure 8). The use of such literary devices is balanced in the three newspapers, though EP uses these devices the most and NYT the least.

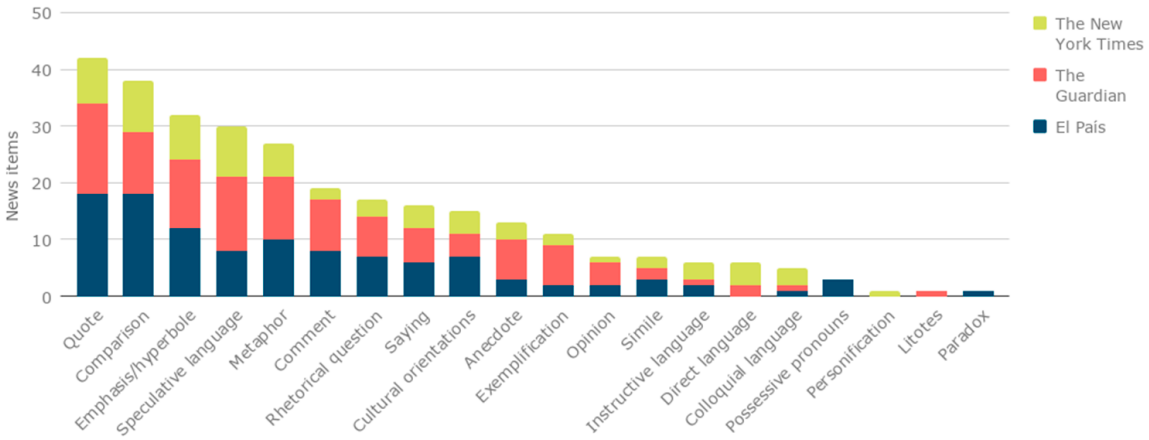

Figure 8. Quantification of the literary devices used in the articles.

Most literary devices and expressions were used to describe graphene's configuration and properties. Table 2 displays the most common adjectives, expressions, phrases, and sentences used to define the material, its properties, and its performance.

Table 2. Adjectives and Expressions Used to Define Graphene, Its Properties, and Its Performance in the News Items Analyzed.

	Adjectives	Expressions, Phrases, and Sentences
Definition	Amazing	The wonder material
	Superb	The super material
	Fascinating	Extremely promising
	Unstoppable	Sent from heaven
	Magic	The apple of the eyes of physicists worldwide
	Divine	The material that could not possibly exist
	Prodigious	The new technological manna
	Fashionable	At the limits of imagination
	Ideal	The latest craze in materials science
		Potentially the most important discovery of the century
		Everything about graphene begs to be inscribed in a legend
Properties and performance	Extraordinary	[The large number of properties found in graphene are]
	Exceptional	extremely rare to find in one material
	Unique	Marvelous behavior
	Unmatched	Outstanding performance
	Unusual	The promise of graphene
	Surprising	The graphene fever
	Intriguing	Industrial game-changer
		Could have an application in almost anything
		One of the most useful materials for future use
		Under a lot of pressure to perform [due to expectations and excitement about the material]

The most common phrase used to describe graphene in the three newspapers was "the wonder material." Some articles dubbed the phenomenon of exaltation and excitement surrounding the material "the graphene fever." Others observed that, due to all these expectations, graphene was "under a lot of pressure to perform."

Comparisons and metaphors were especially used in descriptions of graphene's properties. Table 3 presents the comparisons and metaphors found in the news items regarding specific properties of the material.

Table 3. Comparisons and Metaphors Used to Define Graphene's Main Properties.

Property	Compared to	Metaphors

Resistance	Steel	100 to 300 times stronger/tougher/more resistant than steel
	Diamond	20 times stronger than diamond
	Other conductors	Stronger than other conductors
	Kevlar	Twice as bullet-proof as Kevlar
		The strongest material ever measured
		So tough that a cat could swing in a graphene hammock that would weigh less than one of its whiskers
		If scaled up to the thickness of plastic refrigerator wrap, a sheet of graphene stretched over a coffee cup could support the weight of a truck bearing down on a pencil point
Electrical conductivity	Copper	Like copper
	Silicon	Much better than copper
	Photons	20 times better than copper
		A million times better than copper
		100 to 200 times faster than silicon, consuming much less energy and producing less heat
		Electrons resemble in their behavior relativistic particles without mass, such as photons
		The speed of electrons is 300 times less than that of light, one million meters per second
		A kind of sea of electrons on the surface
Thickness	Human hair	The thinnest material on earth/in the universe
	A sheet of paper	A million times slimmer than a human hair
		One ounce of the material would cover 28 football fields
		Three million of these sheets stacked on top of one other would stand just one millimeter high

Crystalline, hexagonal configuration	Chicken wire Honeycomb	Atomic-scale lattice A molecular chicken wire lattice in which each carbon atom joins three adjacent atoms forming a pattern A two-dimensional honeycomb structure/formation
Color and transparency	Coal Other conductors	Black as coal [in its powder form when gathered inside a container] More transparent to visible light than any other known conductor Resembles nothing so much as breath on a windowpane
Flexibility	Rubber Other conductors Silicon	More flexible/stretchable/bendable than rubber More stretchable than other conductors One of the most pliable materials Graphene can stretch by 20 percent while still remaining able to conduct electricity, while silicon can only stretch by 1 percent before it cracks
Lightness	Feather Steel	The lightest material in the world Light as a feather Six times lighter than steel

In addition to the properties listed in Table 3, the articles also concurred that graphene exceeded all other materials in thermal conductivity and exceeded metal and diamonds in hardness. To define its impermeability, it was written that graphene's high density meant that gases such as helium or hydrogen could not pass through it and that it could be submerged without oxidizing.

Discussion

Analysis of the Results

The fact that no articles about graphene were published during the first years (2004–2006; Figure 1) is likely due to the initial lack of knowledge about the material's importance outside the scientific community. In 2010, Andre Geim and Konstantin Novoselov were awarded the Nobel Prize in Physics for their scientific discovery (Novoselov et al., 2004). This coincided with the first peak of articles appearing in EP and TG (Figure 1) as well as being the year with the highest percentage of news stories mentioning the material's discovery (Figure 2). The award led to large investments in the United Kingdom and Europe and sparked the launch of the Graphene Flagship three years later (Hirsch, 2015). The second news peak in EP's and TG's coverage of graphene coincided with this launch in 2013, so it is not surprising that 2013 saw a high percentage of articles about research and funding. In the following years, much coverage was devoted to the development of applications (Figure 2), which is directly related to the scientific advances that have been developed in research centers funded by the Graphene Flagship (Ferrari et al., 2015; Graphene Flagship, 2015).

In the NYT, these two milestones are not reflected in the number of articles published. The only notable peak in NYT coverage occurred in 2017. This imbalance is surely not due to external events but rather to internal affairs at the newspaper. In 2014, *The New York Times* transferred scientific news to *The Science Times*, and it is possible that the newspaper's internal operations changed. To analyze this radical change in the volume of stories more concretely, it will be necessary to continue studying the publication tendencies in subsequent years.

Regarding the authorship of the news items, most of the articles published about graphene were written by each newspaper's staff. However, we do find a difference between NYT and the other two papers; NYT only published staff content, while EP and TG included news written by external sources, other news services, and readers. In EP, 23% of news items were external, and in TG, 32% were external. The treatment of the news items reveals that the newspaper with the most external sources is also the one with more in-depth articles (TG). In addition, TG is published in the country where graphene was first isolated (Novoselov et al., 2004).

Figure 2 reveals that EP and TG have a similar distribution in the subtopics treated, with research/funding the most discussed, followed by applications. In contrast, NYT mentions applications more than the other subtopics, followed by the material's features. Apart from the year of the discovery (2010), 2009 is the only year that exhibits a different distribution in the quantity of text dedicated to each subtopic. In 2009, graphene's features are highlighted much more than research/funding and applications. We can attribute this to the fact that, in 2009, only NYT published one news article (Figure 1), and it focused on the presentation of the material in society. Only one news item had been published in that same newspaper two years earlier, and Geim and Novoselov had not yet been awarded the Nobel Prize. Therefore, little was known about graphene at that time.

On the other hand, the geographic focus of the articles (Figure 3) reveals that Europe—and the United Kingdom in particular—is arguably establishing itself as the global center for graphene. This is signified by the fact that, among all the articles analyzed, the United Kingdom is the country mentioned the most. In addition, most TG news items have a domestic approach. NYT focuses mainly on international news, and EP has equal numbers of articles with an international and a national approach. The three countries—the United States, the United Kingdom, and Spain—are pioneers in the production of and research on graphene worldwide (Nixon, 2015; Phantoms Foundation, 2015), but China and India are also pioneers, and they are not mentioned as often as the first three countries. China is the country/continent highlighted fifth most—after the United Kingdom, the United States, Spain, and Europe—and India is not named at all. Asia is cited in some of the news items, but less than countries such as South Korea, Sweden, and Germany. Many more European countries are mentioned than those on other continents, most likely because two of the analyzed media organizations have a European origin.

The number of articles that cite each of graphene's properties is about the same in the three newspapers, with only small variations (Figure 4). The properties referred to most are resistance and electrical conductivity, followed by thickness and flat-hexagonal configuration. These four properties are also discussed by scientists in the road maps they draw about graphene (Ferrari et al., 2015; Mertens,

2015; Novoselov et al., 2012). In fact, all four properties are interconnected because they are related to graphene's structure and composition and the benefits that these characteristics provide.

The fact that the most mentioned market sectors are electronics and devices (Figure 5) indicates industry's clear interest in the development of these types of applications. These results coincide with the sectors that Novoselov himself considers the most interesting for the material (Novoselov et al., 2012).

Graphene's most mentioned properties and sectors are not far apart. Graphene's thickness and flat configuration as well as its transparency and flexibility are valued for the development of electronic devices that are adaptable to multiple formats, with little weight and volume (Novoselov et al., 2012). In addition, graphene's light weight makes it noteworthy and attractive for transportation and daily-life applications. The environment and medicine sectors seek a nontoxic, environmentally friendly material with remarkable physical and chemical properties (Novoselov et al., 2012), and graphene's properties of quantum scale, chemical resistance, and chemical properties are often cited in the news items. We can therefore establish a relationship between the market sectors and material properties that are most often discussed in the newspapers analyzed.

Our qualitative assessment reveals that graphene's discovery has generated expectations and promises for the future, which are evident in the distribution of the articles based on the tone of the discourse (Figure 6). The expressions used to emphasize the material's advantages are constant throughout the news coverage. However, there is an increasing tendency toward balanced and critical views of the material. In 2010, coinciding with the Nobel Prize award, all the articles about graphene were positive. As of 2013, coinciding with the launch of the Graphene Flagship (Hirsch, 2015), a more realistic view of the material and its potential began to appear.

In discussing the negative aspects of graphene, each newspaper focused on the aspects most affecting its own country (Figure 7). TG focuses mainly on economic factors, possibly related to the impact of Brexit and the resulting uncertainty in funding research projects. On the other hand, EP mainly highlights scalability, the need for time to introduce the material in commercial applications, and the difficulty in obtaining quality graphene. This situation may be related to the fact that Spain is a leading producer of graphene (Nixon, 2015; Phantoms Foundation, 2015). Finally, NYT notes the difficulty of production and the slow adoption of the material by industry as the primary negative aspects, both of which are points of interest to the United States as a leader in graphene-related patents (Intellectual Property Office, 2015).

Literary devices such as quotes from scientists specialized in the field of graphene were used in many articles to bring consistency to the writing (Figure 8). Comparisons and metaphors (Boeynaems et al., 2017; Kueffer & Larson, 2014) were used to define the material's properties, noting similarities between graphene and other materials such as steel, diamond, or silicon. Hyperbole and speculative language helped emphasize the material's potential. In discussions of the research, production, and development of graphene applications, there was a tendency in the news stories toward speculation about the future, always with a great deal of optimism. This also means that graphene is under pressure to meet future expectations. As a result, articles highlight competitiveness on a global scale, with much emphasis placed on Europe as the

epicenter of graphene's scientific and technological development (Hirsch, 2015; Van Woensel & Archer, 2015).

General Remarks

Since scientists use the media as a vehicle to inform society (Dudo & Besley, 2016), the responsibility that falls on the media is substantial. This analysis has shown reasonable coherence between what scientists say and what the media say. However, the evaluation of the tone of the discourse uncovered that most of the news items principally transmitted the positive features of graphene, paying little attention to the negative aspects. Through the process of agenda setting, the media suggest not only the topics society should talk about but also the terms people should use to discuss them (Boumans et al., 2018; McCombs, 2004). If the media continue using words and expressions such as "divine" or "sent from heaven" to describe graphene and mostly conveying only the positive aspects of the material, the communication of science is not fully effective. Journalists are not being completely honest, and the information is biased. As communicators, we should not let these terms be the ones that the public uses.

We must not forget that gatekeeping is one of media's main roles (Eveland & Cooper, 2013; Shoemaker & Vos, 2009) and that the adaptation of language is an important task of journalists and other communicators (Cortiñas Rovira, 2008; Kueffer & Larson, 2014; Luzón, 2013). A large number of comparisons and metaphors were collected from the news items analyzed, and most of them easily conveyed properties of graphene by drawing comparisons with concepts and images already familiar to general audiences—such as a honeycomb lattice or chicken wire. However, further research is needed to determine whether these metaphors and comparisons maximize understanding or distract readers from the main topic.

Of the three newspapers analyzed, TG offers an interesting perspective regarding the sources and treatment of its news items. It is the one with the most news items from external sources and more in-depth articles. We believe this is a good strategy to achieve better knowledge transfer (Johnson, 2005), because content from a scientific source is more reliable and the terms are more appropriate. In addition, in-depth articles are usually longer than general articles, so a topic can be discussed more extensively.

These remarks all point to the same direction: to evaluate and assess quality in the communication of information about graphene. NYT, TG, and EP are three important news corporations at a global scale (ComScore, 2018) that are used to communicate science topics. However, achieving quality in the communication of complex scientific advances such as graphene is not a straightforward task (Medin & Bang, 2014), not only because in-depth research and language translation needs to be done but also because journalists tend to magnify science, presenting it as something magic, heroic, and distanced from society (Bucchi, 2013). We have observed in this study that this tendency is common in most of the news items analyzed, and we agree with Bucchi (2013) that quality in science communication should be the first concern for all parties involved.

Conclusions

This article presents a quantitative and qualitative content analysis of news stories about graphene published in *El País*, *The Guardian*, and *The New York Times* from October 2004 to October 2017.

In answering RQ1, we found that the three newspapers published approximately the same number of articles about graphene—EP published 26, TG 22, and NYT 19. The distribution of these articles followed different trends over the years. First, the Nobel Prize being awarded to the scientists who discovered graphene led to stories about the material appearing in the newspapers in a meaningful way in 2010. Second, the launch in 2013 of the Graphene Flagship coincided with an increase in the number of articles to 14, up from six in 2012.

Examining the authorship of the news articles to answer RQ2, we found that TG uses a greater variety of sources and provides more in-depth treatment of the topic. The paper is also based in the United Kingdom, where graphene was first isolated (Novoselov et al., 2004).

RQ3 asked about the thematic focus and content of the stories about graphene. The most prevalent subtopic in all the articles was research, followed by the development of applications. The three newspapers shared this common focus on the material's future and potential. The view of Europe as a knowledge superpower and the epicenter of graphene's development was also shared. The material was described in all articles as a great scientific and technological advance, with unique and exceptional properties never found to date in any other material. Graphene's resistance and electrical conductivity were the most cited properties, mentioned in 37 and 35 articles, respectively; electronics and devices were the sectors with the greatest interest, mentioned 74 and 73 times, respectively.

The qualitative analysis to answer RQ4 noted the wide use of literary devices to transform scientific language into a language understood by nonspecialized audiences. Additionally, none of the three newspapers gave a balanced view of graphene; they all focus on the material's advantages rather than its disadvantages. The only negative aspects highlighted were mainly related to the industrialization of the material.

This content analysis of online media helps reveal how information about graphene is transmitted to the public and which resources journalists use to transform scientific language to a more understandable language. The importance of this recontextualization is such that it is crucial to be careful with metaphors and expressions, since the media act as information gatekeepers by setting the public agenda and disseminating the terms people should use when discussing a topic. Therefore, quality is essential in science communication to achieve good knowledge transfer. Overall, we can affirm that the news items analyzed are coherent with the information that scientists publish about graphene. However, the tone in most of the news items is so positive that expressions such as "sent from heaven" are used to describe graphene's properties. We highly recommend journalists and other communicators carefully choose appropriate language in future news articles about graphene.

As more discoveries and advances take place in the field of graphene, more articles will be written about the material. For this reason, we believe that articles published in the three newspapers examined here should continue being analyzed to confirm whether the material meets the expectations of scientists, the press, and society as a whole.

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