Bibliometric Network Densification Patterns for Three Renewable Energy Technologies

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I. Introduction

The aim of this paper is to explore and illustrate a possible use of densification, a metric derived from network theory, to shed light into the evolution of three renewable energy technologies. The combination of the statistical analysis of publications (bibliometrics) [1] and network analysis allows monitoring technological developments [2] and can be used for the identification of emerging topics [3][4][5]. Renewable energy has been addressed by the European Commission [6] and in bibliometric studies e.g. [7][8][9].

On offshore wind energy, Tsai et al. (2016) identified technology development priorities [10], and Gao et al. (2016) reviewed worldwide progress of wind power prices [11]. On solar photovoltaics, thermodynamics fundamentally limit efficiency, and there is much research on alternative approaches to improving efficiency and/or production costs. Enhanced Geothermal Systems (EGS, providing energy from deep fractured rocks) is an emerging technology requiring significant development to reach commercial readiness, with innovation so far limited by costs, exploration risks and technological improvement needs. Kacham et al. (2012) provide insights into technological developments and emerging trends [12].

II. Methodology

This study used the JRC's Tools for Innovation monitoring (TIM) software to retrieve bibliometric data on emerging renewable energy technologies [13]. TIM counts activity levels and uses network analysis to identify and visualise relationships between entities publishing scientific content. We used TIM to retrieve information from the SCOPUS database about scientific publications and entities in wind energy, photovoltaics and geothermal energy.

Boolean search strings in the TIM tool were designed to retrieve documents containing specific keywords in the title, abstract or keywords of publications (ti_abs_key) in a limited period in time (emm year), as exemplified below.

With regard to wind energy the searches focus on the blade component and on offshore wind support structures, which are expected to have a strong influence on future cost reduction and thus attract the attention of present and future R&D efforts.

On solar photovoltaics (PV), we did searches on Perovskite solar cells, a rapidly expanding field highlighted by experts as promising significant efficiency and cost breakthroughs [14][15], and on their precursor Dye Sensitised Solar Cells (DSSC).

Subject	Search query examples
Blades (wind)	ti_abs_key: ("blades" AND "wind turbine") AND emm_year:[1996 TO 2015]
Perovskites (photovoltaic)	ti_abs_key: (perovskite AND (photovoltaic OR "solar cell" OR "solar PV" OR "solar power")) AND emm_year:[1996 TO 2015]

TIM draws its network graphs based on the publication counts (size of the nodes) and co-occurrence of documents by two entities (edges). The properties of the network graphs were used to identify patterns of densification based on yearly counts of edges and nodes.

III. Results and Discussion

Table 1 below indicates the periods and total counts of authorships and entities retrieved by TIM, showing highest counts for DSSC and wind blade technologies. The first retrieved publications date from 2001-2002 for DSSC and offshore structures, and from 1996-1999 for the other technologies. For perovskite solar cells, the first peer-reviewed paper is documented to be from 2009 (cited in [14] and retrieved by our search), although our TIM search also retrieved three 1999 [16][17][18] papers on photovoltaic properties of lead zirconate titanate, a ceramic perovskite material able to produce electric charge.

To gain insight into growth patterns of the technologies investigated, we used TIM to plot their network densification patterns, defined by Bettencourt et al. (2009) as a correlation between edges and nodes following a simple power law:

$$y = kx^{\alpha} \quad (1)$$

where y is the number of edges, x the number of nodes and k and α are constants. The exponent α describes the densification of a scientific field. Topics that show high densification exponents ($\alpha>1$) grow and tend to have shared fields of collaboration and exchange, whereas fields without a solid proof of concept show low values ($\alpha \sim 1$) [2].

Table 1: Investigated renewable energy technologies: periods of investigation, counts of retrieved authorships and publishing entities. *Constraints: Starting year when cumulated edges and nodes each > 1; authorship counts account for co-publication by multiple entities; counts are indicative as of March 2017

Technology	Search field/Search string	Period*	Authorship counts*	Entity counts,~ 2015*
Wind energy	Offshore support structures	2002-2015	1730	620
Wind energy	Blades	1996-2015	8510	2430
PV solar cells	Perovskites	1999-2015	3380	1350
PV solar cells	Dye sensitised (DSSC)	2001-2015	10850	2770
Geothermal energy	Enhanced Geothermal Systems	1996-2015	1090	540

Table 2: Densification exponents of the performed search queries

Search field	Densification exponent α	R^2
Offshore wind support structures	1.33	0.993
Blades for wind energy	1.34	0.989
Perovskite solar cells	1.20	0.993
Dye sensitised solar (DSSC)	1.46	0.994
Enhanced Geothermal Systems	1.02	0.980

Figure 1 below shows densification plots (cumulative counts of new entities publishing and of authorships) and power-law regression fits for the five technologies. The densification exponent (hereunder α) is ca. 1.35 to 1.45 for the relatively more established wind and DSSC technologies, which also feature steeper gradients (stronger densification) in Figure 1. For the more emerging EGS and perovskites α is 1 and 1.2, indicating more moderate densification. The more linear plots for the wind and DSSC technologies indicate more constant densification. Yearly publication counts are also more regular for these further densifying technologies (α > 1.3), and more intermittent for the emerging ones (α ≈ 1), as exemplified below.

For EGS, densification increases around 2007-2009 and 2012-2014. This corresponds roughly to the opening of the first EGS international demonstration power plant at Soultz (FR) in 2007, followed by the 2009 introduction of a renewable energies law in Germany, and by proof-of-concept EGS projects starting to produce electricity from 2012.

For perovskite solar cells, fabrication simplicity plus similarities with dye-sensitized and organic photovoltaics resulted in a rapid increase in the number of researchers working in this field in the past few years [15]. Indeed our search indicates a sharp burst in publication counts for 2014-2015, following efficiency breakthroughs significantly higher than for the best-reported DSSCs [14].

IV. Conclusions

We used the JRC-developed TIM tool for bibliometric analysis of three renewable energy technologies and exported results to calculate network densification metrics as defined by Bettencourt [2].

For the technologies examined, our results from network theory and bibliometric analysis provide potentially relevant metrics for mapping these technologies according to their developmental stage. As foreseen, higher densification exponents (α >1.3) do correspond to technologies with more established collaboration networks, while lower densification exponents (α ≈ 1) are obtained for more emerging technologies. The level of granularity of the technologies seems to be adequate and the approach could be applied to a wider range of upcoming renewable energy technologies.

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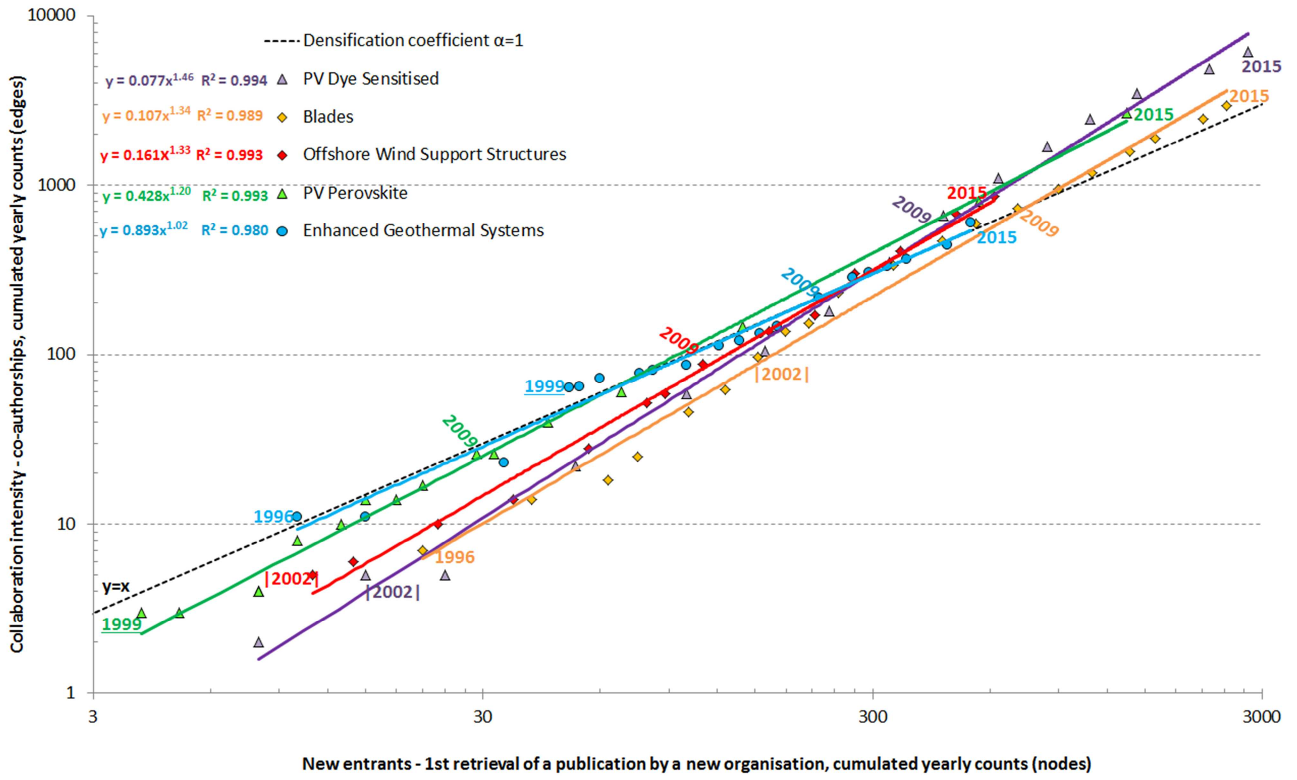

Figure 1: Densification of collaboration graph of the searches for wind, photovoltaics and geothermal energy (cumulative figures).

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