LEAP-RE T5.3

Scientometric Analysis of Renewable Energy Research-Capacity in Africa

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Contents

Abstract

The present report displays the results of the scientometric study on the renewable energy research-capacity in African countries by focusing on the publications in the 10 years range between 2011-2020. In order to deliver a comprehensive overview, after the analysis of the African countries in their respective African Union regions and international co-publication networks, the study has been broadened into organisational co-publication networks of the selected countries as well as the analysis of the most visible research areas and keywords/ keyword pairs from the selected organisations. Moreover, as a further point of view, renewable energy related publications from the African countries are also categorised under distinct research domains to show the most visible organisational pairings as well as most visible and trending keywords/ keyword pairs in different clusters of scientific areas.

LEAP-RE

Long-Term Joint EU-AU Research
and Innovation Partnership on Renewable Energy

Chapter 1

Introduction

This study mainly focuses on renewable energy (RE) related research in African countries between 2011-2020. The study has been carried out under the project LEAP-RE[1] (Long-Term Joint European Union - African Union Research and Innovation Partnership on Renewable Energy) *Task 5.3: Strategy for RE research-capacity in Africa* with the co-lead of MESRS (Ministry of Higher Education and Scientific Research)[2] and ZSI (Centre for Social Innovation)[3].

The results, which will be displayed in the following chapters, are generated through a cleaned, normalised and recategorised dataset created with the data collected from the Clarivate's Web of Science[4] databases. A comprehensive discussion about the methods can be found in Chapter 2.

Following the explanation of the methodology in the next chapter, Chapter 3 displays the results of the study. After showing the overall figures in Section 3.1 which include a general overview of the yearly RE-related publication output in the African continent, the most visible countries and organisations as well as the distribution of research domains and areas, Section 3.2 focuses on individual African Union Geographic Regions[5]. The regional analysis generally deals with the most visible countries in each region as well as their co-publication networks which also include interregional (partnerships with other African countries from other regions) and intercontinental (partnerships with countries from other continents) collaborations. Furthermore, the analysis also focuses on selected countries in each region to display the most visible organisations and organisational

[1] https://www.leap-re.eu/

[2] https://www.mesrs.dz/

[3] https://www.zsi.at/

[4] https://www.webofscience.com

[5] The 5 African Union Geographic Regions; Northern Africa, Western Africa, Central Africa, Eastern Africa, and Southern Africa have been defined by the Organisation of African Unity in 1976 (CM/Res.464QCXVI). A list of countries in each region can be found under https://au.int/en/member_states/countryprofiles2.

co-publication networks as well. The regional analysis also includes at least 1 selected organisation from each selected country to present the most visible research areas and keyword/keyword pair networks on the organisational level. Finally, Section 3.3 approaches the RE research in Africa from another direction and by splitting publications into research domains in order to discuss the most visible co-publication pairings between organisations as well as most visible keywords/ keyword pairs in each distinct cluster of scientific areas.

The report will be delivered in 3 different formats. An HTML-File which includes the whole scope of the report with interactive visualisations, a PDF-File which is content-wise identical to the HTML-File with static visualisations instead of interactive. And a dashboard where the results will be displayed in a compact mode interactively.

Chapter 2

Methodology

This chapter mainly deals with the explanation of the methodological definitions, information about the data collection, preprocessing, analysis, and visualisation/ report writing phases.

2.1 Definitions

Research Area/ Research Domain. Research areas are the scientific fields defined by the Web of Science (WoS). Research domains are the 5 parent categories (Physical Sciences, Technology, Life Sciences & Biomedicine, Social Sciences, Arts & Humanities) of the research areas [1].

Co-publication. A publication that has been produced with the collaboration of at least 2 authors from 2 different organisations.

Interregional co-publication. Interregionality in this Report refers to different African countries from different African Union (AU) regions. An interregional co-publication, therefore, is a paper published with the collaboration of at least 2 authors from African organisations from different regions of Africa.

Intercontinental co-publication. Co-publications of at least 2 organisations located on different continents.

Relative growth rate. A simple indicator of how many folds the number of publications has been increased in comparison with the number of publications in the start year (2011). The equation is simply:

$$rel\_growth\_rate := end\_value/start\_value$$

[1] Web of Science's categorization of research areas under research domains can be found under https://images.webofknowledge.com/images/help/WOS/hp_research_areas_easca.html.

2.2 Data Source & Methodological Steps

The study is based on the data from Clarivate's Web of Science (WoS) databases. After the unification of the collected RE-related keywords, different types of search queries have been tested on WoS. A search query with over 80% accuracy for the identification of RE-related research has been determined through sampling processes.

The data collected from WoS databases through the decided search query have been turned into a common dataset for the use of all partners collaborating in the study. The generated dataset has been transformed by preprocessing steps like data cleaning, normalisation, reduction, and categorisation. The normalisation of the organisation names is done with the help of the Global Research Identifier Database (GRID)[2].

Following the preprocessing steps, an exploratory data analysis has been carried out and some of the key figures have been visualised to decide for focus points of the study between the partners.

Further data analysis has been carried out accordingly to the joint decision on the report format/ outline planning and visualisations have been designed to work interactively.

[2] https://www.grid.ac/

Chapter 3

Results

Following clarification of the motivation and methodology of the scientometric analysis on the renewable energy (RE) related research in Africa, this chapter is dedicated to the presentation of the results under the following 3 sub-chapters:

1. Overall Figures
2. Regional Analysis
3. Domain Analysis

After delivering a general overview on yearly output, the most visible countries and organisations as well as distribution of scientific domains and areas in the RE-related publications in African countries between 2011-2020, *Regional Analysis* focuses on each of the 5 regions (Northern Africa, Western Africa, Central Africa, Eastern Africa, Southern Africa)[1] individually. Analysis of the geographic regions include:

- Most visible countries.
- Regional, interregional, and intercontinental collaboration networks of all countries in the region.
- Collaboration networks of the academic organisations in *selected countries*[2].
- Analysis of the most visible research areas and the correlation network of the keyword/keyword pairs in the RE-related publications of the *selected organisations*[3].

[1] A list of the countries in each African Union region can be found under https://au.int/en/member_states/countryprofiles2.

[2] The two deciding factors for the selection were, firstly, the total RE-related publication output, and secondly, the relative growth in the number of RE-related publications.

[3] Selection criteria were the same as the criteria for countries.

Domain Analysis approaches RE-related research in Africa from a different perspective by analysing the publications under the 5 research domains Physical Sciences, Technology, Life Sciences & Biomedicine, Social Sciences and Arts & Humanities[4]. Analysis of each domain includes:

- Most visible inter-regional/ intercontinental collaborations between academic organisations.
- Most visible and trending keywords/ keyword pairs.

3.1 Overall Figures

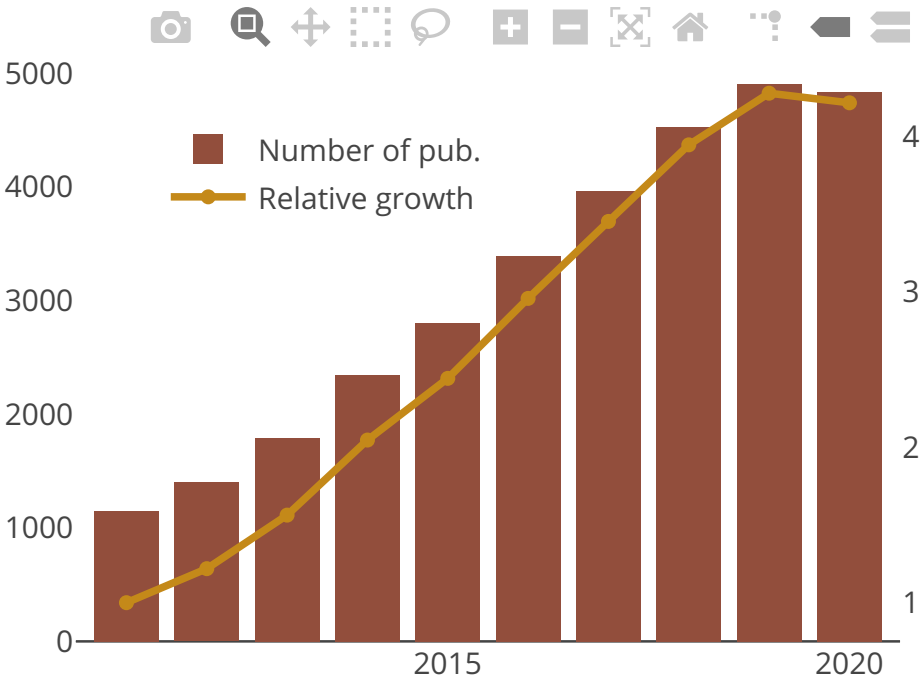


Figure 3.1: Number of RE-related publications in African countries over the years between 2011-2020

African countries have collaborated in approximately 31k renewable energy (RE) related publications in the 10 years range between 2011-2020. The number of those publications has been constantly increasing until 2019. Slightly declining

[4]Web of Science's research area/domain classification can be found under https://images.webofknowledge.com/images/help/WOS/hp_research_areas_easca.html. Because of the fewer number of publications, Social Sciences and Arts & Humanities have been analysed together.

publication numbers between 2019 and 2020 (see Figure 3.1) is likely caused by the latency in the database entries [5] according to the explanation of Web of Science. Even after including the possibly incomplete amount of publications in 2020, the number of RE-related publications from the African countries in total increases from ~1.1k in 2011 to ~4.8k in 2020 which is an increment by factor ~4.2.

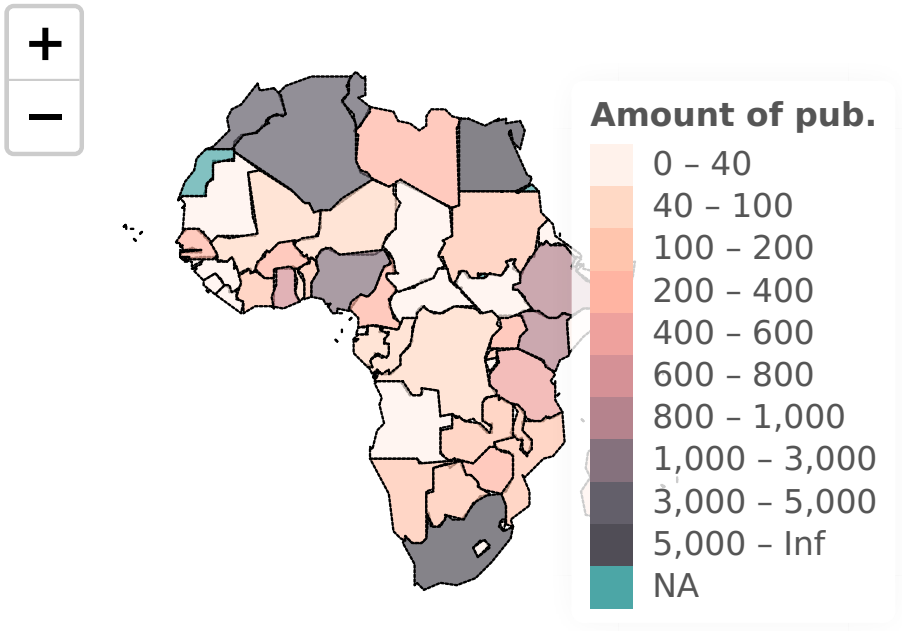


Figure 3.2: Total number of RE-related publications in African countries between 2011-2020

As Figure 3.2 shows, South Africa and Egypt are the most visible countries with 6.8k and 6.6k RE-related publications respectively. 20 African countries stay under 40 RE-related publications in total between 2011-2020. The most visible countries are distributed diversely on the continent, however, other than the Northern African countries and South Africa only Nigeria contributed to over 1000 RE-related publications (2252 pub.) between 2011-2020.

Although total publication output is a strong indicator of the most visible countries, it does not show the growth rate in the numbers. African countries that show a high increment rate in the number of publications despite having a relatively lower total amount of publications will be analysed in the following chapter.

[5] As the Web of Science support service informs, it might take up to 2 years for a document to be entered into the Web of Science databases.

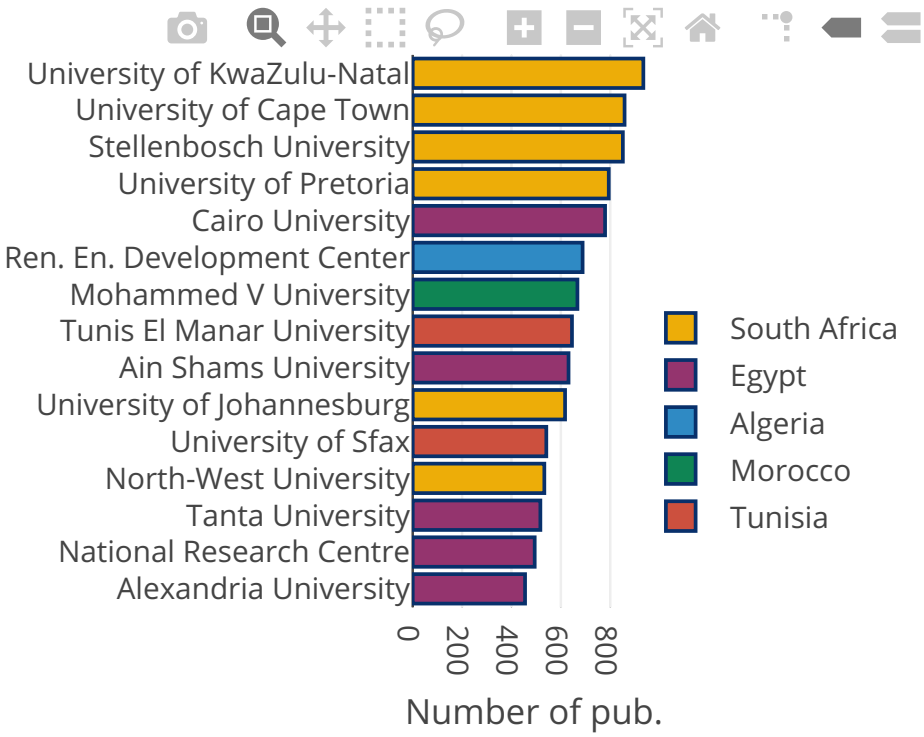
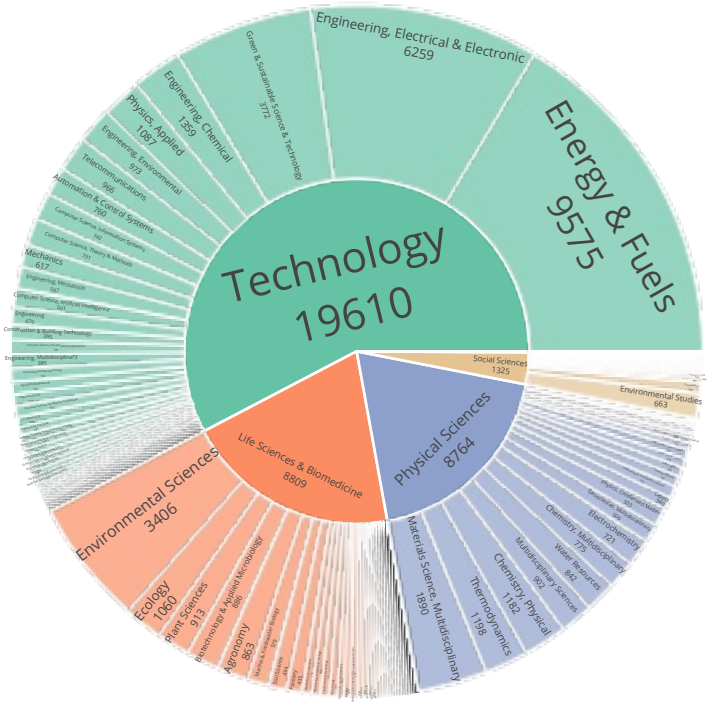


Figure 3.3: Most visible 15 African countries in RE-related publications between 2011-2020

4 of the most visible 5 organisations (*University of Kwazulu-Natal*, *University of Cape Town*, *Stellenbosch University*, and *University of Pretoria*) in RE-related publications are located in South Africa. Each of them has close to or over 800 publications between 2011-2020, Cairo University from Egypt is following them with ~780 publications. 4 other Egyptian institutions; namely Ain Shams University, Tanta University, National Research Centre of Egypt and Alexandria University are also among the 15 most visible organisations.

Tunis El Manar University and the *University of Sfax* from Tunisia are also in the most visible 15 organisations with ~650 and ~550 RE-related publications and *Mohamed V University*, the only organisation from Morocco in the list has ~670 RE-related publications.

Although most of the visible organisations are in general universities, the only organisation from Algeria in the most visible 15 organisations, namely *Renewable Energy Development Center* is an institution completely dedicated to RE-related research. The total number of RE-related publications of *Renewable Energy Development Center* is ~700 between 2011-2020.



[6]

Over 50% of the RE-related publications are associated with research areas from the *Technology* domain. *Energy & Fuels* is the most visible research area

[6] A single publication may be associated with multiple research domains/ areas. The sum of the number of publications in individual research domains/areas does not add up to the total number of publications.

in total followed by *Electrical & Electronic Engineering*. Other Engineering fields like *Chemical, Environmental, Mechanical Engineering* are also among the visible research areas. Multidisciplinary discipline *Green & Sustainable Science & Technology* is the 3. most visible research area in total.

Life Science & Biomedicine and Physical Sciences have a similar number of publications (~8800 pub. both). *Environmental Science* and *Ecology* from Life Sciences & Biomedicine as well as *Multidisciplinary Materials Science* and *Thermodynamics* from Physical Sciences are also in the 10 most visible research areas.

Social Sciences (1325 pub.) is also not absent in the RE-related publications of African organisations. *Environmental Studies* is the most visible research area in this domain with 663 publications.

The 5. research domain Arts & Humanities include only 45 publications, therefore, this domain will be analysed together with Social Sciences in Chapter 3.3 Domain Analysis.

3.2 Regional Analysis

Following the overall figures of the RE-related publications in Africa, this section introduces the geographical regions of Africa to broaden the analysis further. Focusing on different regions of Africa prevents the over-representation of already relatively more visible countries in terms of publications and also enables a detailed analysis for individual countries and organisations.

To determine the African regions, this study uses African Union Geographical Regions[7] instead of the United Nations Statistics Department[8] (UNSD). A presentation of the African Union regions can be seen in Figure 3.4.

As Figure 3.5 summarizes, 4 of the most visible African countries in the RE-related publications are from Northern Africa. South Africa has the highest number of RE-related publications (~6900) between 2011-2020, only other member country of Southern Africa in the most visible 15 countries is Zimbabwe with 230 RE-related publications between 2011-2020. Nigeria, Ghana, Senegal from Western Africa; Ethiopia, Kenya, Tanzania, Uganda from Eastern Africa; and Cameroon, the only country from Central Africa, are among the 15 most visible countries following the most visible 5 countries.

3.2.1 Northern Africa

Member countries of Northern Africa have collaborated approximately in half of the total number of all RE-related publications (17116 publications out of

[7] https://au.int/en/member_states/countryprofiles2
[8] https://unstats.un.org/unsd/methodology/m49/

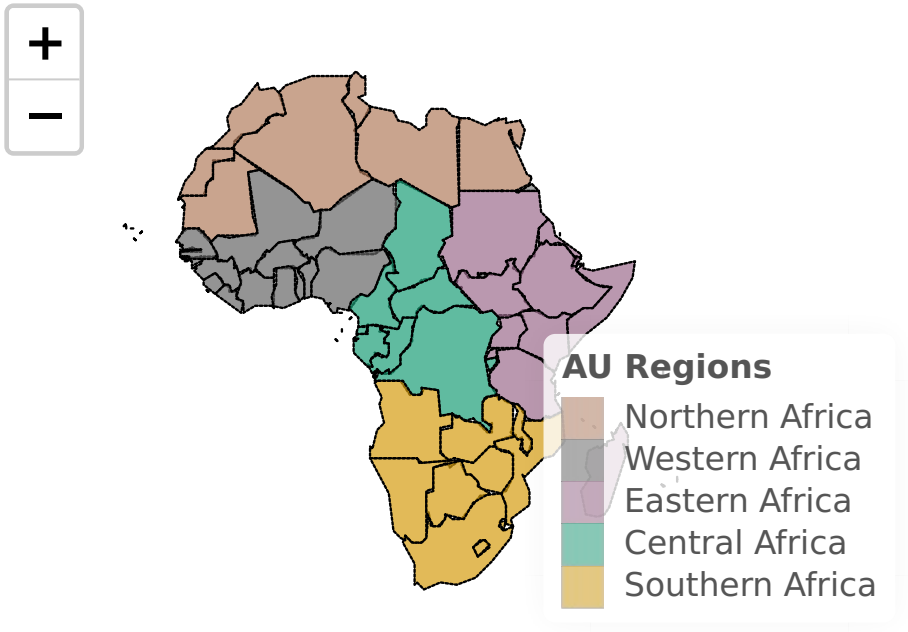


Figure 3.4: African Union Geographic Regions

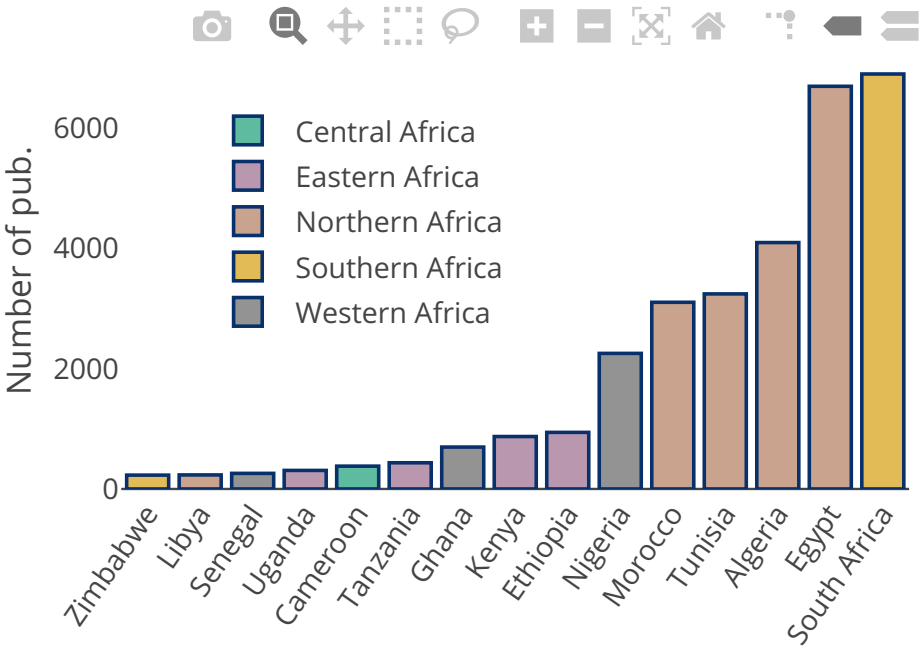


Figure 3.5: The most visible 15 African countries in RE-related publications between 2011-2020

Country	2011		2020	Rel. growth rate (2011-2020)	Total num. of pub. (2011-2020)
Egypt	218		1344	6.17	6689
Algeria	152		412	2.71	4093
Tunisia	127		383	3.02	3240
Morocco	34		543	15.97	3101
Libya	4		32	8.00	233

Figure 3.6: RE-related publication output in the most visible Northern African countries

31099) in Africa between 2011-2020. 4 of the 5 most visible African countries in RE-related publications are from the northern region; namely Egypt, Algeria, Tunisia and Morocco.

As Table 3.6 presents, all of the Northern Africa countries increased their number of RE-related publications until 2017. Although, as discussed in the previous chapter, slight declines in the number of publications between 2019-2020 are most likely caused by the delay of document entry into the Web of Science databases, Algeria and Tunisia show an earlier start of the decline in their number of publications starting in 2017 and 2018 respectively. In the case of Libya, however, volatility in the number of publications is expected as their total publication outputs are relatively lower.

Another important observation is in the relative growth rates [9], Morocco's number of RE-related publications in 2020 are approximately 16 times higher than the number in 2011. This growth rate is not only the highest in Northern Africa but in the whole continent among the most visible countries in RE-related research.

RE-related co-publications of the Northern African countries show a rich international network but the collaboration with other African regions seems to be relatively less dense. Only African countries from other regions which have co-published over 25 RE-related papers with Northern African countries are South Africa (28 pub.) and Nigeria (26 pub.).

Egypt, the most visible country in Northern Africa in terms of RE-related publications, plays a central role in the network with ~6.6k publications in total. The relatively uniform distributed co-publication network of Egypt includes over 10 EU-27 countries as well as a number of countries from other regions of the world like the USA, China, India, United Kingdom. Egypt's strongest link in the co-publications, however, is with organisations from Saudi Arabia.

Tunisia, Algeria and Morocco have relatively high numbers of collaborations with French organisations with 751, 881 and 601 co-publications respectively. France in general is the most visible EU-27 country in the RE-related co-publications with African countries. Out of France's ~3250 RE-related co-publications with African countries ~2350 of those have been published with the collaboration of Northern African countries whereas Algeria and Tunisia being the most visible Northern African countries in those collaborations. The closest following EU-27 country in terms of RE-related co-publications is Spain (~580 out of ~820 co-publications with African countries) and Germany (~490 out of 1334 co-publications with African countries).

The 4 mentioned Northern African countries so far, Egypt, Algeria, Tunisia and Morocco are co-publication-wise relatively well interconnected, however, Libya stays out of the co-publication cluster in Northern Africa, from Libya's

[9] Relative growth rate value in this report does not indicate a percentage as it is usually calculated, instead the equation is simply $end\_value/start\_value = growth\_rate$.

*Collaboration links with fewer than 25 co-publications have been removed.

Figure 3.7: Co-publication network of Northern African countries in RE-related publications between 2011-2020

Organisation	2011		2020	2020)	202
Cairo University	29		128	4.41	7
Ain Shams University	22		104	4.73	6
Tanta University	9		124	13.78	5
National Research Centre	28		93	3.32	4
Alexandria University	19		74	3.89	4

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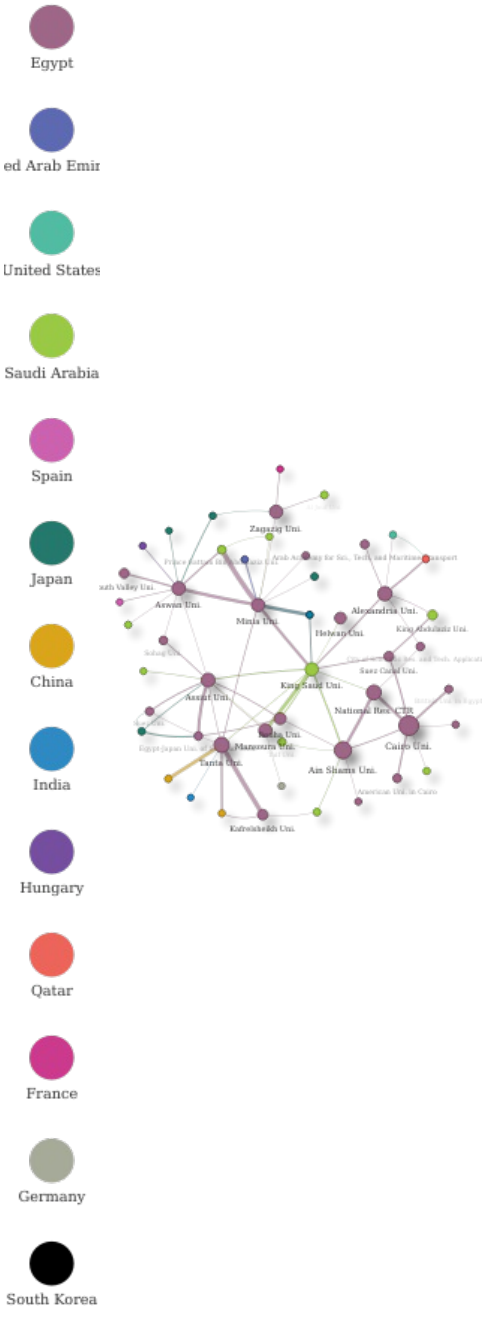
The most visible Egyptian organisation in the RE-related publications is *Cairo University* with a total of 779 publications between 2011-2020. All of the most visible 5 organisations of Egypt display a fairly linear growth in the number of RE-related publications. However, Ain Shams University and Tanta University show a stagnation between 2019-2020 which might be caused by the delay of document entries into the Web of Science system as mentioned above. Furthermore, Tanta University, which had yearly fewer than 50 RE-related publications until 2016, published in 2019 and 2020 ~125 RE-related papers, this is a growth rate of ~14 fold with respect to the 9 publications in 2011.

The Co-publication network of Egyptian organisations shows a relatively dense collaboration structure between *Cairo University*, *Ain Shams University* and *National Research Centre* of Egpyt. *National Research Centre* has over 50 co-publications with each of the other universities in that cluster. *Cairo University* is also in the centre of other 4 Egyptian organisations; namely *Suez Canal Uni.*, *British Uni. in Egypt*, *Zewail City of Sci. Tech* and *American Uni. in Cairo*, with over 20 co-publications each.

Other visible collaboration links are between *Minia* and *Aswan Universities* with over 50 publications and between *Tanta* and *Kafrelsheikh Universities* with over 70 publications together. In general, collaborations with organisations from Saudi Arabia are highly visible in the network, especially *King Saud University* is a central node in the network with ~400 RE-related co-publications with Egyptian organisations.

Other than that, East Asian organisations also have a visible presence in the co-publication network of Egypt. *Tanta University*'s collaborations with Chinese Institutions *Jiangsu Uni.* and *Huazhong Uni* include 60 and 40 co-publications respectively. Several Japanese universities have collaborations with *Aswan University*, *Zagazig University*, *Assiut University*, *Suez University*, *Egypt Japan University* and *Minia University* with over 20 co-publications each. *Minia University*'s collaboration with South Korean institution *JeonBuk National University* also includes 60 RE-related co-publications between 2011-2020.



*Collaborations with fewer than 20 co-publications have been removed

Figure 3.8: Co-publication network in RE-related publications in organisations from Egypt between 2011-2020

Visible organisations from EU-27 countries are *Université Bourgogne Franche-Comté* of France (over 25 co-publications with *Zagazig University*), *Ruhr University Bochum* from Germany (22 co-publications with *Mansoura Uni.*), *Budapest University of Technology and Economics* from Hungary and the *University of Jaen* from Spain (both over 25 co-pub. with *Aswan University*).

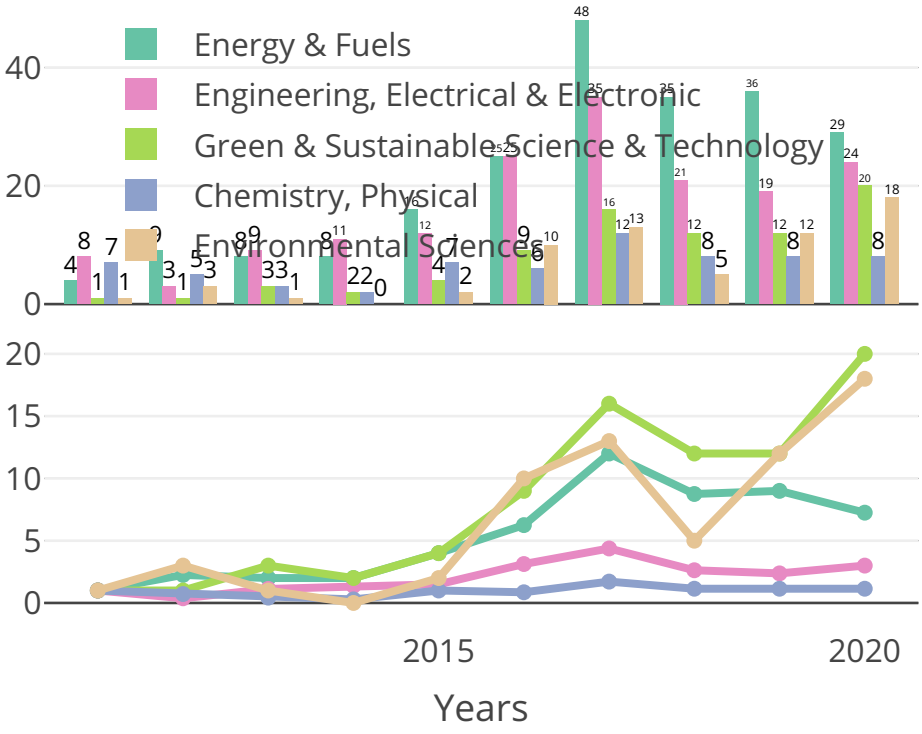


Figure 3.9: Absolute and relative growth of the most visible research areas in RE-related publications from Cairo University between 2011-2020

3.2.1.1.1 Cairo University Looking into the most visible research areas of *Cairo University*, out of 779 publications in total, the most visible research areas are aligning with the most visible research areas in RE-related publications from African countries in general. *Energy & Fuels*, as well as *Electrical & Electronic Engineering* are the most visible research areas in Cairo university, however, the number of RE-related in those areas are not growing in the last years. After the spike in 2017 with ~50 publications, the number of publications from *Energy & Fuels* has fallen to ~30 publications in 2019 and 2020. *Green & Sustainable Science & Technology* and *Environmental Sciences* on the other hand display relatively steady growth in numbers. Considering there was only 1 from each area in 2011, ~20 RE-related publications in 2020 makes those the fastest growing research areas in the RE-related publications from Cairo

University.

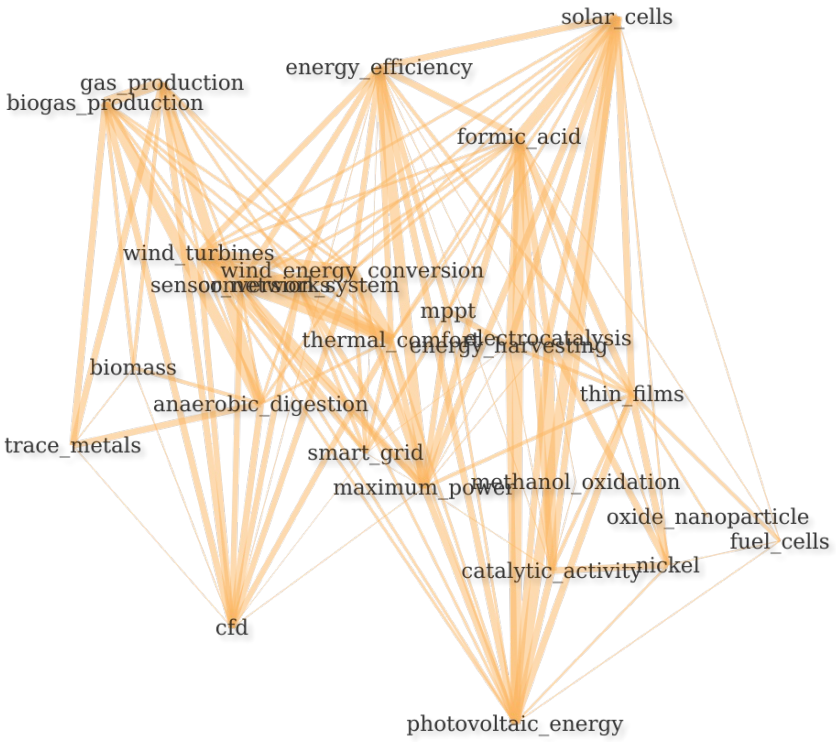


Figure 3.10: Keyword/keyword pair correlation network in RE-related publications of Cairo University

Figure 3.10 displays the correlation network between the most common keywords and keyword pairs in the RE-related publications of *Cairo University*. As the clusters on the network graph indicate, there is a strong emphasis on solar energy, photovoltaic systems related keywords in *Cairo University*'s publications which is widely the case in African countries. In relation, substances and technologies aiming to improve the efficiency of the effectiveness of solar cells like formic acid, MPPT (Maximum Power Point Tracking, an algorithmic DC-DC converter that increases the efficiency of photovoltaic cells) are also among the visible keyword pairs. Other clusters include wind energy-related keywords as well as biogas/biomass related keywords. The approaches like electrocatalysis that aims to increase the output of solar and wind energy are also often mentioned in the RE-related publications of *Cairo University*.

	Polytechnique d'Oran				
	University Ferhat Abbas of Setif	3		29	9.67
	University of Batna	10		25	2.50

3.2.1.2 Algeı

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Renewable Energy Development Center, Algeria's dedicated institution for RE-related research is the most visible Organisation in the country with ~690 publications. However, the number of RE-related publications of the institution is falling after a spike in 2018 with 127 publications. Although the latency in the record entry process in WoS databases might be causing a proportion of the decline, the number of publications in 2020 seems to be less than half of the number in 2018 (54 pub.).

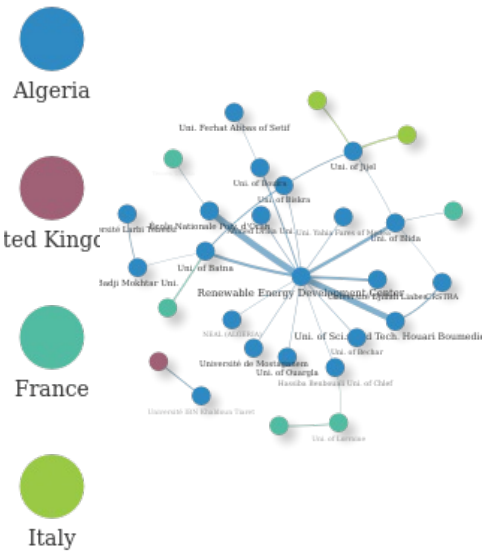
Houari Boumediene University of Sciences is another Algerian institution that publishes RE-related papers consistently. A similar decline in the number of publications like in the case of *Renewable Energy Development Center* can be observed in the publications of *Houari Boumediene University of Sciences* after 2018 (from 75 publications to 44 publications in 2020). *École Nationale Polytechnique d'Oran University*, *Ferhat Abbas of Setif* and the *University of Batna* are other organisations with similar numbers of RE-related publications (259, 241, 239 pub. respectively), each of those has increased their yearly RE-related publication output to ~30. The decline in the number of publications after ~2018 can be observed in all of the most visible 5 organisations of Algeria.

Co-publication network of Algerian organisations mostly gathered around *Renewable Energy Development Center*, the to RE-related research dedicated institution collaborates with a number of other Algerian academic institutions, from which 14 of the collaboration links include close to or over 20 co-publications. The most visible collaborations with *Renewable Energy Development Center* are with *Houari Boumediene University of Sciences* and *École Nationale Polytechnique d'Oran University*, both with an output of over 60 co-publications.

Most of the international collaborators with more than 25 co-publications with Algerian institutions are French, the collaboration between *University of Batna* and *University of Picardy Jules Verne* is the most visible one with 27 co-publications between 2011-2020. *University of Jijel* collaborates often with Italian institutions like *University of Trieste* (23 co-pub.) and *International Centre for Theoretical Physics* (28 co-pub.). Other than that, *University of Hertfordshire* is the only organisation from the UK that has more than 20 RE-related co-publications with an Algerian organisation (*University Ibn Khaldon*) between 2011-2020.

3.2.1.2.1 Renewable Energy Development Center

The most visible research areas in the RE-related publications of *Renewable Energy Development Center* are *Energy & Fuels* and *Green & Sustainable Science in Technology*. All of the most visible 5 research areas are declining in numbers after 2018 which indicates that it is most likely caused because of the delaying entry of the publications into the Web of Science databases.



*Collaborations with fewer than 15 co-publications have been removed

Figure 3.11: Co-publication network in RE-related publications in organisations from Algeria between 2011-2020

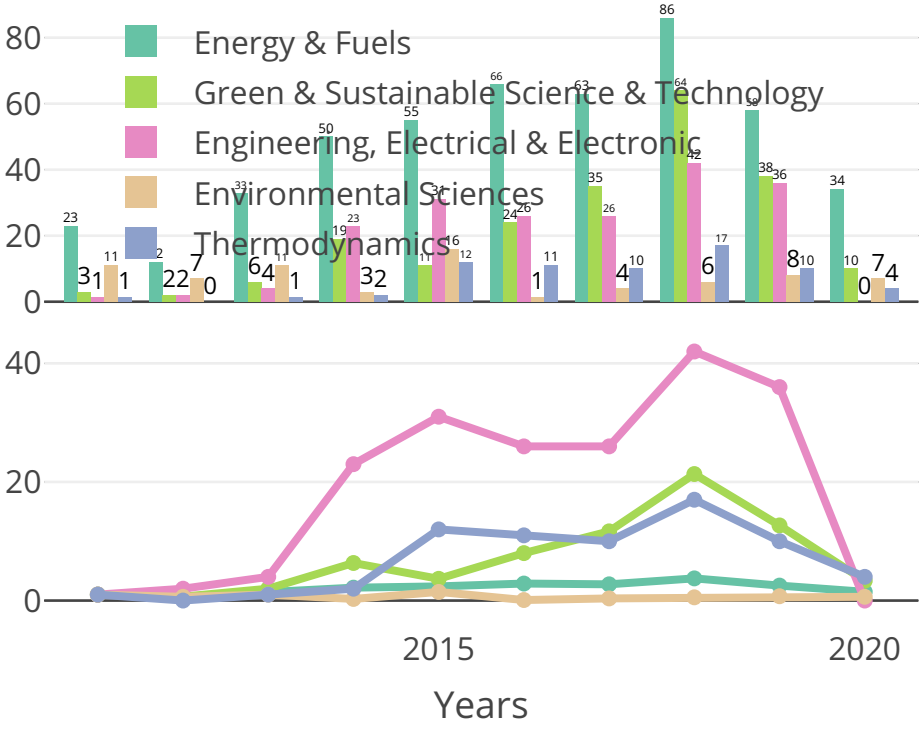


Figure 3.12: Absolute and relative growth of the most visible research areas in RE-related publications from Renewable Energy Development Center between 2011-2020

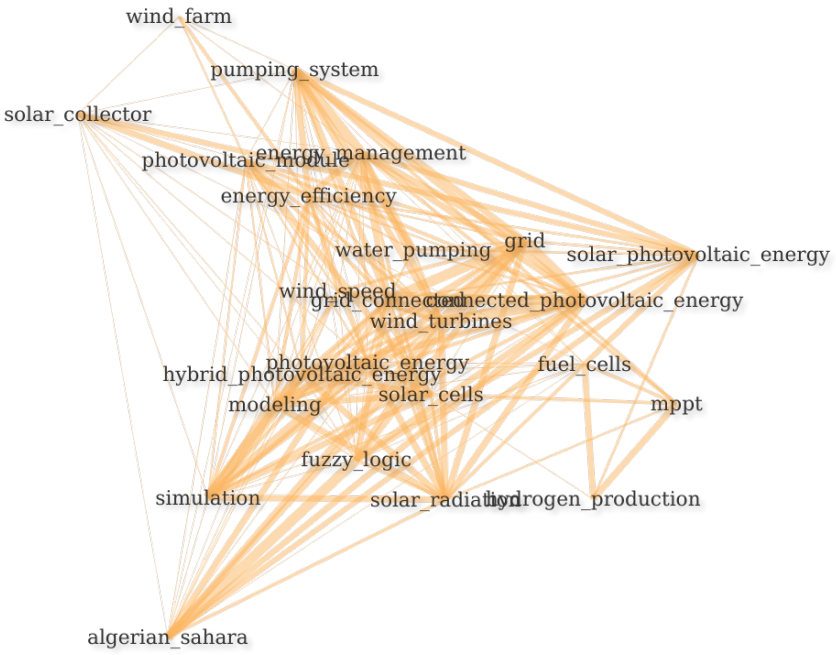


Figure 3.13: Keyword/keyword pair correlation network in RE-related publications of Renewable Energy Development center

Organisation	2011		2020	(2011-2020)	(201 202
Mohammed V University	4		104	26.00	6
University of Sfax	9		73	8.11	5
University of Hassan II Casablanca	5		88	17.60	4
Cadi Ayyad University	7		76	10.86	3
Mohamed I University	2		49	24.50	2

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3.2.1.3 Morc

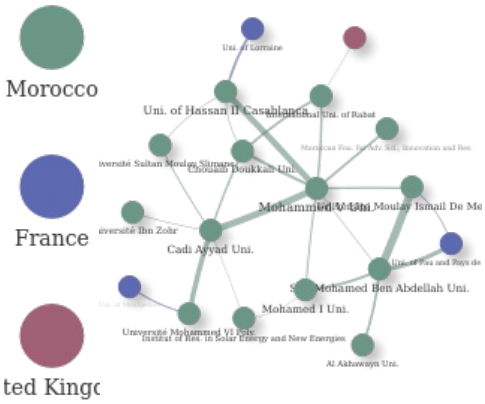
\begin{figure} Morocco has the most rapidly growing number of publications in the 15 most visible African countries in RE-related publications with having 543 publications in 2020 in comparison with 34 RE-related publications in 2011. The same pattern is also observable in the publications of Moroccan Institutions. Each one of the RE-wise most visible 5 organisations in Morocco had 1 digit RE-related publications in 2011 and each of those have published at least ~8 fold of those numbers in 2020.

Mohamed V University is the most visible Moroccan institution in the RE-related publications with 667 publications in total between 2011-2020. There is a slight decline in the number of publications after 2018 but the university still collaborates in over 100 RE-related publications yearly. *Mohamed V* and *Mohamed I Universities* are both published in comparison with 2011 ~25 times more in RE-related papers. The *University of Sfax*, *University of Casablanca* and *Cadi Ayyad University* are most visible 2., 3. and 4. organisations respectively

Moroccan organisations are well interconnected in RE-related publications. Although *Mohamed V University* stays in the centre of the network, institutions are evenly distributed. Especially the number of co-publications of *Mohamed V Uni.* with *Cadi Ayyad Uni.* and *Uni. of Hassan II Casablanca* (41 and 39 co-publications respectively) as well as the co-publications between *Universite Moulay Ismail de Meknes* and *Sidi Mohamed Ben Abdellah Uni.* (~50 co-publications) are most visible collaborations in Morocco.

Only a few intercontinental collaborations have an output of more than 15 co-publications with Moroccan organisations. *Uni. of Lorraine*, *Uni. of Montpellier* and *University of Pau and Pays de l'Adour* from France, *Uni. of Leeds* from the UK are the most visible intercontinental collaborators.

3.2.1.3.1 Mohammed V University Similar to the other selected universities from the Northern Africa region *Energy & Fuels* has a strong presence also



*Collaborations with fewer than 15 co-publications have been removed

Figure 3.14: Co-publication network in RE-related publications in organisations from Morocco between 2011-2020

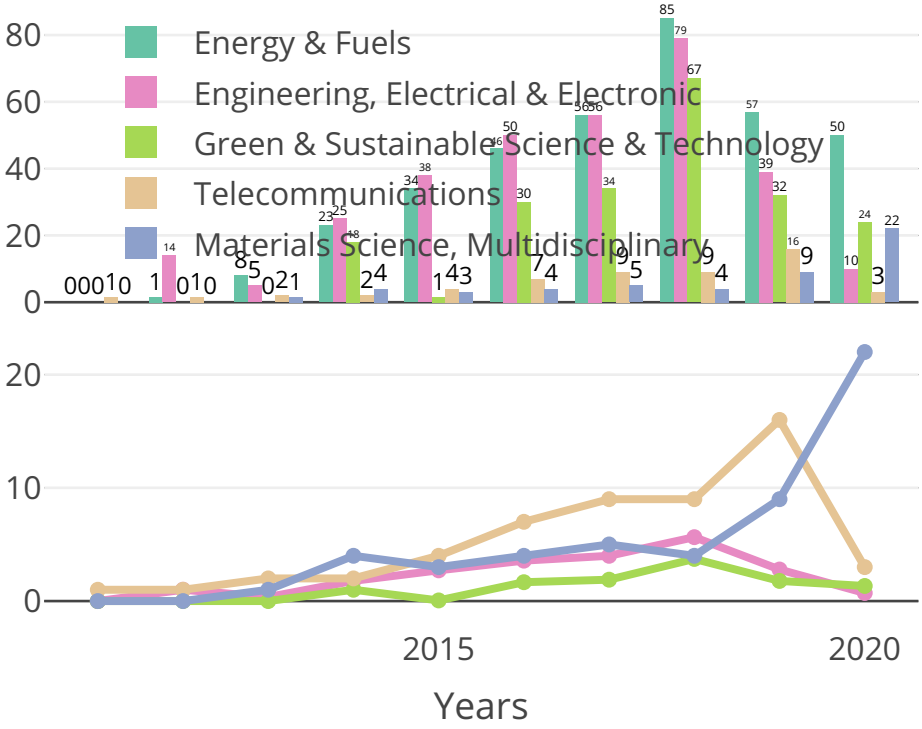


Figure 3.15: Absolute and relative growth of the most visible research areas in RE-related publications from Mohamed V University between 2011-2020

in the publications of *Mohamed V Uni.*. Considering, there was no recorded renewable energy-related publication from *Mohamed V Uni.* in 2011 and only 1 publication in 2012 in Web of Science databases, 2018 shows a strong contrast with 85 RE-related publications to the previous years. *Electrical and Electronic Engineering* is following *Energy and Fuels* closely in total RE-related publication from *Mohamed V Uni.*.

Although, there are no recorded publications in *Green and Sustainable Science & Tech.* before 2014, it stays as the 3. most visible research area in the total numbers. In contrast to the other selected organisations so far one of the most visible research areas in the RE-related publications from *Mohamed V University* is *Telecommunications* and publications in *Multidisciplinary Material Science* are also increasing since 2015. *Multidisciplinary Material Science* is also the only research area that was increasing in numbers between 2019-2020 in the RE-related publications of *Mohamed V University*.

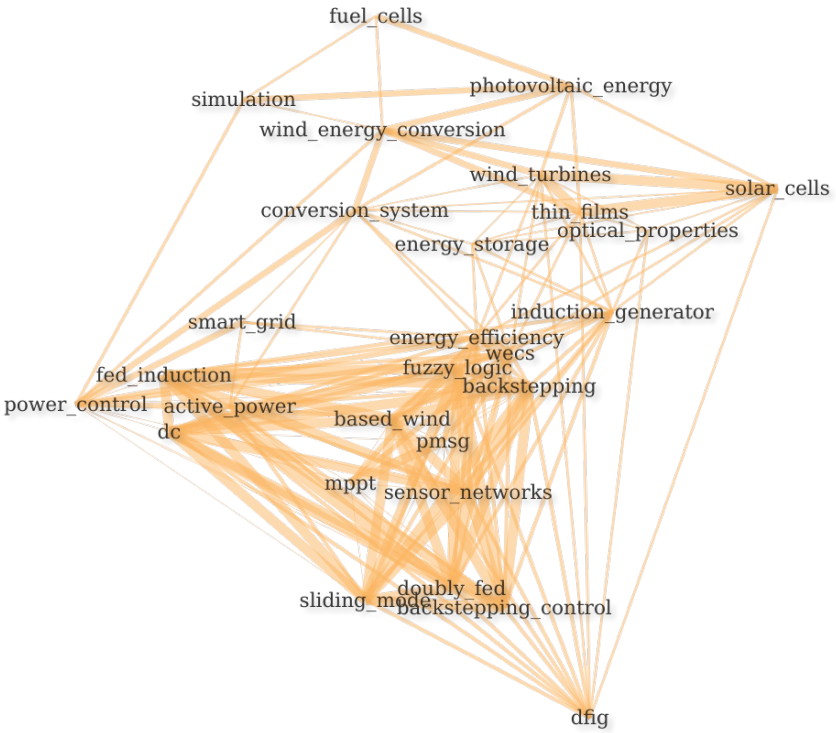


Figure 3.16: Keyword/keyword pair correlation network in RE-related publications of Mohammed V University

The keyword/keyword pair correlation network of *Mohamed V University* also includes a number of solar energy and wind energy-related themes. Especially different types of conversion systems (wind energy conversion systems) are reoccurring patterns in the RE-related publications of *Mohamed V University*. In relation, hybrid energy approaches like *doubly fed induction generator* (dfig) or backstepping control system that supports wind tribunes and photovoltaic systems (see **?**) are emphasized. Also, dc-dc converter technologies like MPPT that aims to increase the efficiency of the photovoltaic systems are among the most visible keywords.

3.2.2 Western Africa, Central Africa, Eastern Africa

Western Africa, Central Africa and Eastern Africa are corresponding to a vast area of the African continent, however, on organisational level number of RE-related publications are relatively fewer in comparison. Therefore, although on country level those 3 regions will be analysed individually as in previous sub-chapters, on organisational level; firstly, table of most visible organisations will include organisations from selected 3 countries from each region and organisation network they will include all 3 regions on a single graph.

3.2.2.1 Western Africa

Western African countries Nigeria and Ghana have been increasing their RE-related publication output in a consistent manner in the 10 years range (see table 3.17) without any stagnation. Although Nigeria's number of publications in 2011 was already relatively high in comparison (74 pub.), the number of publications in 2020 was ~6.5 fold (481 pub.) of that. In a similar fashion, Ghana has increased its RE-related publication output from 20 in 2011 to 153 in 2020 which is an increment of a factor of ~7.5.

Senegal, the third most visible country in the region shows a volatile progression with a sharp decline in the number of RE-related publications after 2018 from 48 yearly publications to 28. Burkina Faso is following Senegal with relatively less volatility and Benin's volatile numbers are expected since the total output of RE-related publications is fewer in comparison.

Nigeria, the highest of the region in terms of the total number of RE-related publications, is also the centre of mass in the co-publication network of the Western African countries. It is the only Western African country with more than 25 co-publications with a Northern African country (Egypt, 26 co-pub). In a similar manner, together with Ghana, Nigeria is the only Western African Country with more than 25 co-pub. with South Africa (277 pub.).

Ghana and Nigeria have a collaboration link with 40 RE-related co-publications between 2011-2020. However, the collaborations between the two most visible countries in the region with the other countries are relatively sparse. Côte

Country	2011		2020	Rel. growth rate (2011-2020)	Total num. of pub. (2011-2020)
Nigeria	74		481	6.50	2252
Ghana	20		153	7.65	696
Senegal	13		28	2.15	259
Burkina Faso	11		30	2.73	222
Benin	13		16	1.23	162

Figure 3.17: RE-related publication output in Western African countries

*Collaboration links with fewer than 25 co-publications have been removed.

Figure 3.18: Co-publication network of Western African countries in RE-related publications between 2011-2020

Covenant University	9		37	4.11	250	N
University of Ibadan	7		25	3.57	197	N
University of Nigeria	4		46	11.50	185	N
Kwame Nkrumah University of Science and Technology	4		30	7.50	166	G
University of Ghana	7		32	4.57	140	G

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\begin{figure} All of the most visible 3 organisations in the Nigeria, Ghana, Senegal cluster are from Nigeria. The number of RE-related publications from *Covenant University*, the most visible organisation in the region, seems to be declining presumably because of the latency in document entries into WoS databases after 2019.

Other than *Covenant University* total RE-related publication outputs of other most visible organisations in Western Africa are relatively close to each other. The *University of Nigeria* has the highest relative growth rate of 11.5 (from 4 pub. in 2011 to 46 in 2020). Other than the *University of Ibadan*, the other 3 organisations were also consistently increasing numbers of their Re-related publications despite two Ghanaian organisations showing slightly more volatile progress.

3.2.2.2 Central Africa

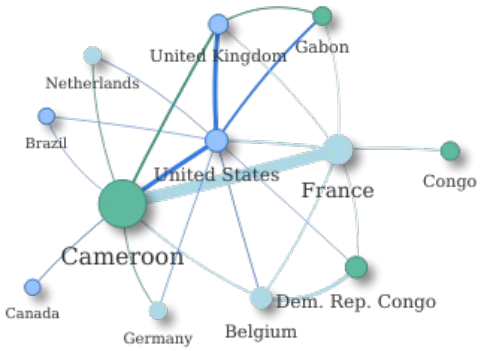
In the Central African region, the publication output in RE-related topics is relatively volatile. Cameroon shows a steady increment between 2011-2020 (see 3.19) with a total output of 379 RE-related publications in 10 years. Other than Cameroon, the total number of RE-related publications in other Central African countries stays under 100.

Although the publication output is not high in comparison with other regions, most of the publications in Central Africa are produced through intercontinental cooperation.
France is the most visible intercontinental collaborator in the co-publication network in Central Africa with 180 co-pub. in the region; 121 of those co-pub. have been published by collaboration with Cameroon. Belgium is following France with ~90 co-pub. with Central African countries.

All of the visible international collaborators have published at least 25 RE-related co-publications with Cameroon. However, none of the Central African

Country	2011		2020	Rel. growth rate (2011-2020)	Total num. of pub. (2011-2020)
Cameroon	13		64	4.92	379
Dem. Rep. Congo	3		19	6.33	97
Congo	5		12	2.40	63
Gabon	4		12	3.00	61
Central African Rep.	2		4	2.00	12

Figure 3.19: RE-related publication output in Central African countries



*Collaboration links with fewer than 25 co-publications have been removed.

Figure 3.20: Co-publication network of Central African countries in RE-related publications between 2011-2020

University of Buea	2		9	4.5
University of Ngaoundéré	1		7	7.0
Center for International Forestry Research	1		8	8.0

countries seems
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\begin{figure} In the Cameroon, Dem. Rep. Congo and Gabon cluster, all of the most visible 5 organisations in the region are from Cameroon with the most visible organisation being *Université de Yaoundé I* with 170 RE-related publications in 2020. None of the organisations in the region has published more than 5 RE-related publications in 2011.

Université de Yaoundé I is followed by *Université de Dschang* which increased its 1 RE-related publication in 2011 to 18 in 2020 with a total of 76 RE-related publications in the 10-year range. The RE-related publication output of the following 3 organisations; *University of Buea*, *University of Ngaoundéré* and *University of Douala* is still fewer than 10 yearly publications.

3.2.2.3 Eastern Africa

Country	2011		2020	Rel. growth rate (2011-2020)	Total num. of pub. (2011-2020)
Ethiopia	28		226	8.07	940
Kenya	32		132	4.12	871
Tanzania	17		62	3.65	435
Uganda	7		53	7.57	308
Sudan	11		28	2.55	191

Figure 3.21: RE-related publication output in Eastern African countries

The most visible 5 Eastern African countries have been steadily increasing their numbers of RE-related publications. Ethiopia and Kenya are the most visible ones with 940 and 870 publications respectively. Ethiopia's number of publications in 2020 (226 pub.) is approximately 8 fold the number in 2011 (28).

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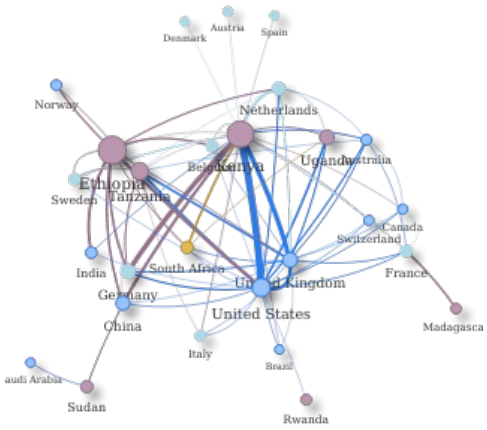
\begin{figure}

Organisation	2011		2020	Rel. growth rate (2011-2020)	Total num. of pub. (2011-2020)	Cou
Addis Ababa University	9		43	4.78	246	Eth
World Agroforestry Centre	6		17	2.83	150	K
Mekelle University	3		28	9.33	135	Eth
University of Dar es Salaam	5		13	2.60	124	Tan
University of Nairobi	4		17	4.25	120	K

Most visible countries from the selected countries in Eastern Africa, namely Ethiopia, Kenya Tanzania are diverse. *Addis Ababa University* from Ethiopia is the most visible one with 246 RE-related publications between 2011-2020. The number of publications from *Addis Ababa University* has been increasing steadily since 2013.

Although *World Agroforestry Centre* operates in different countries, the main location of the institution is registered as Kenya. *World Agroforestry Centre* is the second most visible organisation in the Ethiopia, Kenya, Tanzania cluster with a total number of 150 publications between 2011-2020. However, the yearly number of publications are declining since 2016.

Mekelle University of Ethiopia is the third most visible organisation with steady growth in the number of RE-related publications and *University of Dar es*



*Collaboration links with fewer than 25 co-publications have been removed.

Figure 3.22: Co-publication network of Eastern African countries in RE-related publications between 2011-2020

Salaam is the only organisation from Tanzania in the 5 most visible countries in the selected countries of East Africa followed by the *University of Nairobi* of Kenya.

3.2.2.4 Selected Institutions and Institutional Co-publication Network

Collective organisation network of Western, Central and Eastern African regions displays a couple of interconnected co-publication clusters. Organisations from Cameroon are one of the most visible clusters where *Université Yaoundé I* stands as a central connection node. *Université de Dschang*, *Uni. of Buea* and *Université De Ngaoundéré* are the other academic organisations from Cameroon which co-published visible amount of RE-related publications with *Université Yaoundé I* (22, 17 and 17 co-publications respectively). The network of Cameroonian universities is connected to French and British organisations with a visible amount of publications. On the French side *Uni. of Montpellier* and *CIRAD* both have 22 co-publications with *Université Yaoundé I* and on the other side *Uni. of Leeds* has a collaboration of 18 RE-related co-publications with *Université Yaoundé I* where other British academic organisations like *UCL*, *Uni. of Oxford* and *York Uni.* are also present in a number of those co-publications.

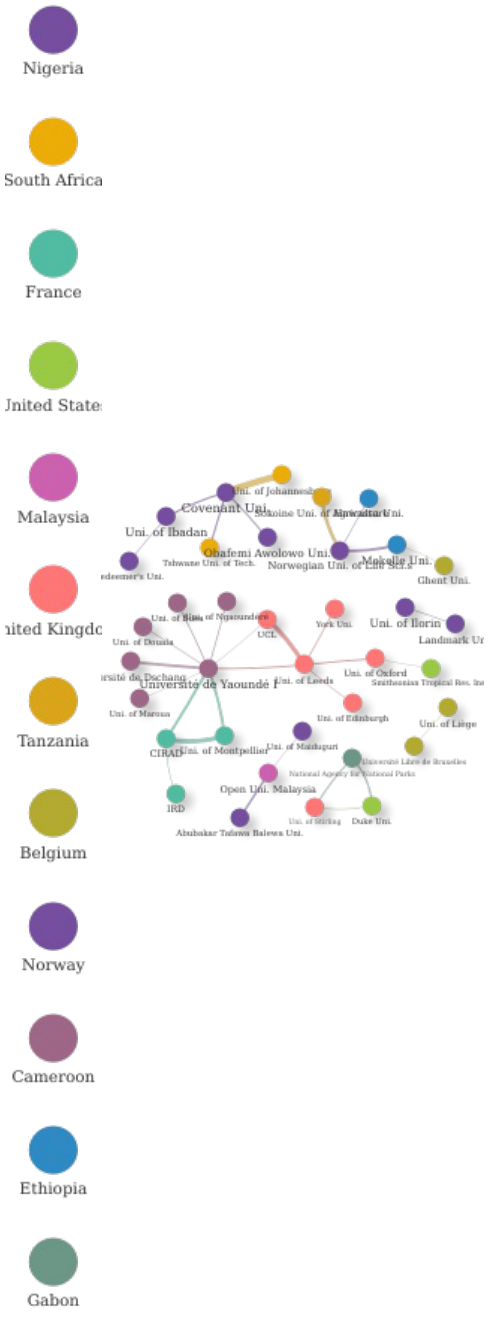
Nigerian Universities form another visible cluster in the co-publication network whereas *Covenant University* plays a central role. *Uni. of Ibadan* and *Obafemi Awolowo Uni.* both have ~20 co-publications with *Covenant University*. Also, *Covenant University*'s collaborations with South African institutions are in the most visible co-pub. connections in the region, *University of Johannesburg* has co-published 34 RE-related publications with *Covenant University*.

Other visible collaborations are *Norwegian Uni. of Life Sciences*' co-publications with Tanzania's *Sokoine Uni. of Agriculture* (24 co-pub.) and with Ethiopia's *Mekelle University* (22 co-pub.).

3.2.2.4.1 Covenant University (Nigeria) The most visible research areas are *Energy & Fuels* and *Green & Sustainable Science & Technology* respectively in RE-related publications of *Covenant University*. 2019 is in terms of RE-related publications a peak point for *Covenant University*, the 2 two most visible areas include 20 and 30 publications respectively in this year.

None of the last three research areas *Multidisciplinary Sciences*, *Material Science* and *Electrical & Electronic Engineering* had more than 1 yearly RE-related publication in *Covenant University* until 2016. However, although there weren't any publications in *Multidisciplinary Sciences* until 2017, the research area has become one of the most visible research areas in *Covenant University's* RE-related publications with yearly over 10 publications.

Similar to the research areas keyword/keyword pair correlation network of *Covenant University* also includes some differing elements. Along with a heavy



*Collaborations with fewer than 15 co-publications have been removed

Figure 3.23: Co-publication network of Western, Central, Eastern African organisations in RE-related publications between 2011-2020

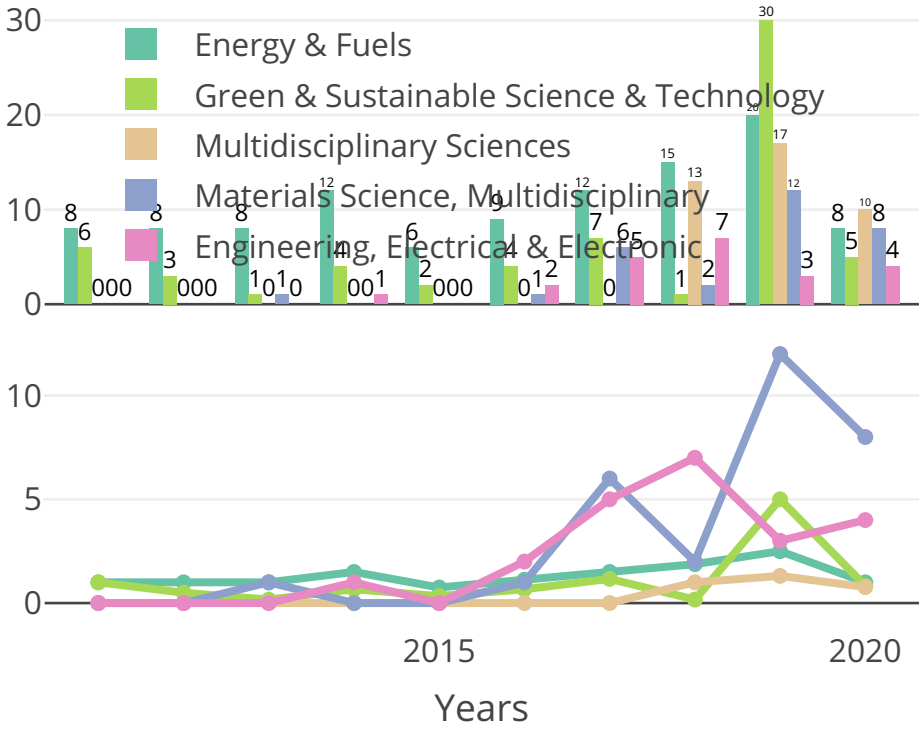


Figure 3.24: Absolute and relative growth of the most visible research areas in RE-related publications from Covenant University between 2011-2020

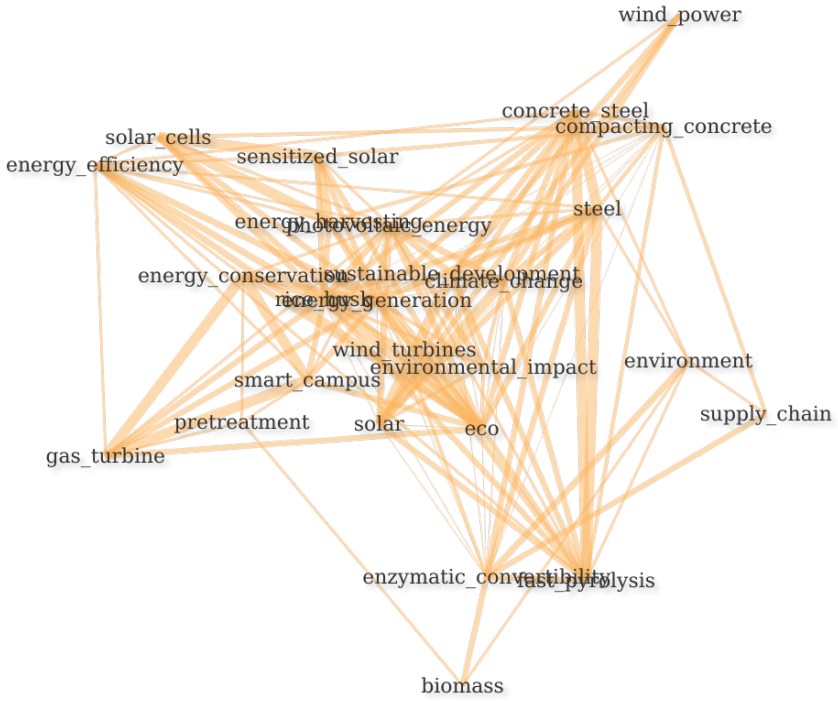


Figure 3.25: Keyword/keyword pair correlation network in RE-related publications of Covenant University

emphasis on solar and wind energy-related topics, one of the central keyword pairs indicates the research on using rice husk, a byproduct of rice growing, as a biomass fuel. Presumably several mentions of concrete and steel, firstly, relates to the production of those materials with renewable energy, and secondly, as *compacting_concrete* indicates research on producing environment-friendly forms of (self-) compacting concrete which has more than one benefit for sustainable development (further reading: **?** and **?**).

Also, keyword pairs like *fast_pyrolysis* and *enzymatic_convertibility* indicate a high number of biomass related studies.

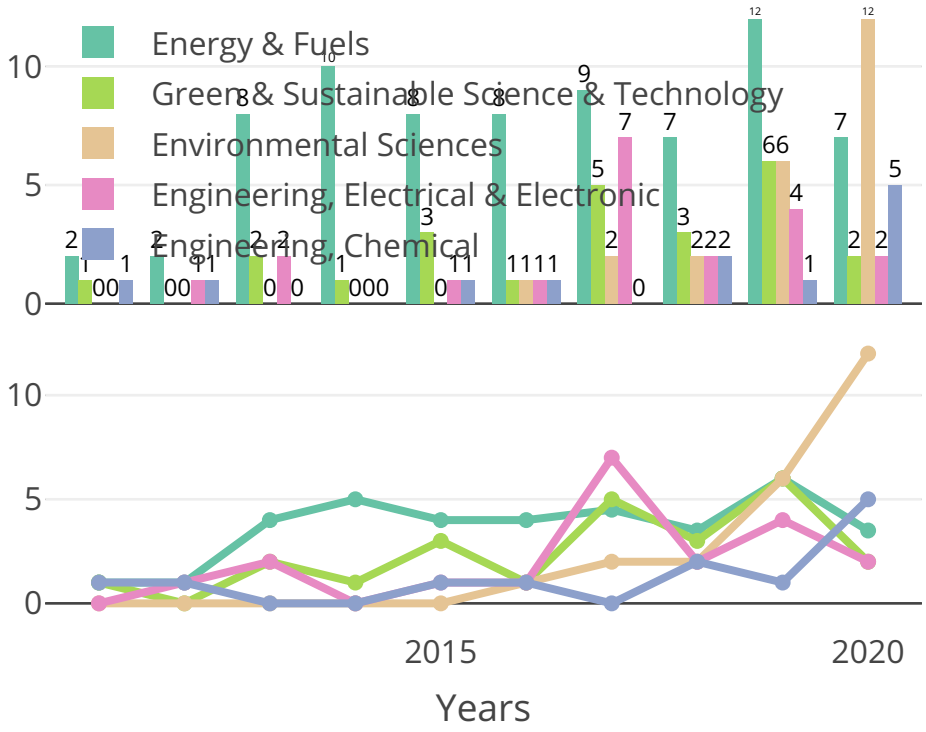


Figure 3.26: Absolute and relative growth of the most visible research areas in RE-related publications from University of Nigeria between 2011-2020

3.2.2.4.2 University of Nigeria The *University of Nigeria* also starts with a fairly low number of publications in the now trending research areas. Until 2013 none of the most visible 5 research areas includes a yearly output of over 2 RE-related publications. Energy & Fuels spikes in the later years followed by Green & Sustainable Science & Technology. However, while the two most visible areas are stagnating or declining Environmental Sciences starts to grow in numbers and become together with Chemical Engineering the only areas still rising in 2020.

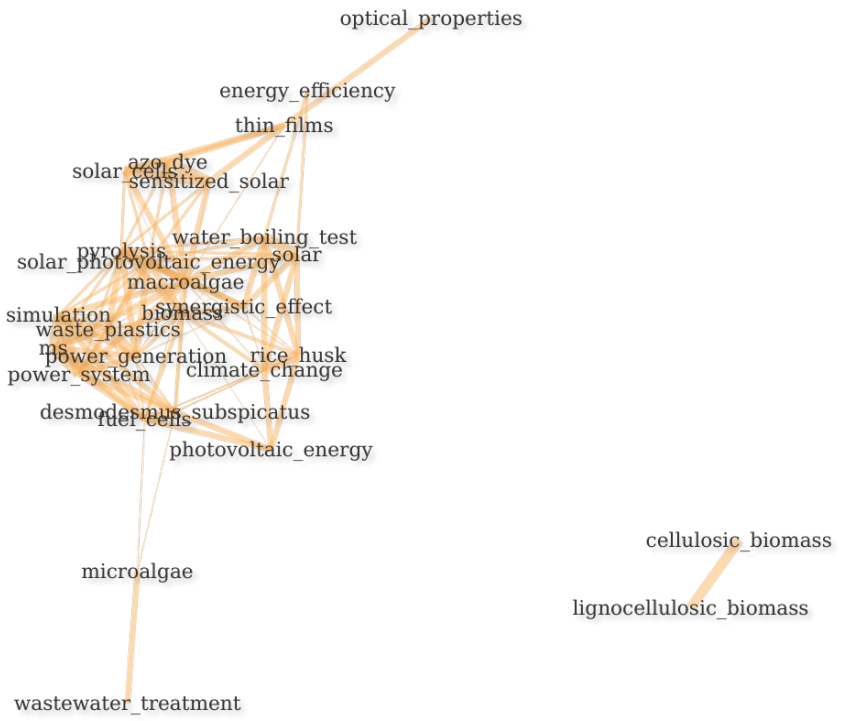


Figure 3.27: Keyword/keyword pair correlation network in RE-related publications of University of Nigeria