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Industrial Smart and Micro Grid Systems – A Systematic Mapping Study

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Abstract:

Energy efficiency and management is a fundamental aspect of industrial performance. Current research presents smart and micro grid systems as a next step for industrial facilities to operate and control their energy use. To gain a better understanding of these systems, a systematic mapping study was conducted to assess research trends, knowledge gaps and provide a comprehensive evaluation of the topic. Using carefully formulated research questions the primary advantages and barriers to implementation of these systems, where the majority of research is being conducted with analysis as to why and the relative maturity of this topic are all thoroughly evaluated and discussed. The literature shows that this topic is at an early stage but already the benefits are outweighing the barriers. Further incorporation of renewables and storage, securing a reliable energy supply and financial gains are presented as some of the major factors driving the implementation and success of this topic.

Keywords:

- Industrial Smart Grid
- Industrial Micro Grid
- Systematic Mapping Study
- Strategic Energy Management
- Industrial Facility Optimization
- Renewable Energy Resources

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1. Introduction:

In the current environmental and economic climate, every available avenue must be explored as we strive to improve efficiencies, gain a competitive advantage and fulfil compliance obligations. In Ireland, emphasis must be placed on meeting the 2020 Energy Efficiency and Greenhouse Gas emissions targets (SEAI, 2016). The further reductions required for 2030 and 2050 must also be considered and acted upon to ensure future compliance and security (SEAI, 2016). For industry, it is becoming increasingly difficult to comply with these regulations and avoid costly fines with traditional fossil fuel energy production or reliance on an out-dated grid supply (Schulze et al., 2016). As a result, many industrial facilities are investing heavily in Renewable Energy Sources (RESs), Distributed Energy Resources (DERs) and Energy Storage Systems (ESSs) on site (Misaghian et al., 2018). The implementation of individual or a combination of multiple RESs aid industrial sites in lowering their lifecycle carbon impact and avoiding the associated fines as well as reducing their effect on the environment and climate change (N. Yu et al., 2016). This operation has many benefits but raises the question of how these various energy sources and storage systems can operate together in harmony. One recurring solution is to incorporate each of these elements into a smart grid system (Li et al., 2016)(Shi et al., 2017).

A smart grid is a modern electric power grid infrastructure system in which advanced information and communication technologies are integrated within the system allowing each component to interact and influence the operation of the others (Ding et al., 2014). This allows the user to take more control of the management of their energy system as well as allowing them to integrate more and more RESs to reduce their emissions and reliance on the grid (Choobineh and Mohagheghi, 2016). For industrial sites it is becoming more common to create, manage and maintain their own energy network where each aspect can be individually controlled (Logenthiran et al., 2011). This micro grid system forms an electrical network structure, which allows the use of further DERs in a secure and reliable way (Misaghian et al., 2018). Micro grids are believed to be capable of promoting the utilization of intermittent renewable energy, relieving the energy crisis and mitigating the contradiction between energy use and environmental protection (Shi et al., 2017). A further benefit of this for industry is that it is possible to operate in islanded mode or grid connected for security and quality of supply (Misaghian et al., 2018). This can be particularly attractive to some industrial facilities as it allows for the more aggressive use of renewable energy generation, combined heat and power (CHP) systems and energy storage devices (Shi et al., 2017). Further opportunities arise for the development of class leading optimisation strategies with the aim of building and maintaining a competitive edge regarding energy efficiency and emission values (Schulze et al., 2016)(Hooshmand et al., 2018)(Blake and O’Sullivan, 2018).

Systematic mapping studies are designed to give an overview of a research area through classification and counting contributions in relation to the defined categories of that classification (Petersen et al., 2015). Using this method of searching through the relevant literature it was possible to create a comprehensive and fully documented evaluation of the current state of industrial smart and micro grid systems worldwide. Using carefully formulated research questions, it was possible to target the specific data that could be used to discuss and evaluate the topic further as well as potentially generate new hypotheses and theories for additional research (Donovan et al., n.d.). As the objective of this paper is to evaluate research trends, knowledge gaps and ascertain leaders in this subject matter it was decided that a systematic mapping approach would provide the most extensive and comprehensive assessment of this area (James et al., 2016). This structured approach to synthesising the information on the state of the topic allows for in-depth analysis of a broad topic with clearly defined outputs and informative illustrations (Donovan et al., n.d.).

Section 2 of this paper presents the methodology and clearly outlines the research questions and processes employed throughout the study in detail. A descriptive analysis of the results is presented in section 3. This illustrates the distribution of research across the specified classifications and highlights significant categories. Section 4 presents the main outcomes of the research and provides a detailed discussion of each key point ensuring a comprehensive assessment of the topic is made. Finally, Sections 5 and 6 offer conclusions and topics for future work.

2. Methodology:

A systematic mapping study methodology was chosen for this paper. The aim was to create an overview of the research area through classification and counting contributions in relation to the defined categories of classification (Zavala et al., 2018). By locating relevant papers and existing case studies based on formulated research questions in this way, it was possible to evaluate and synthesize their contributions. Following this methodology presented the evidence for discussion in a clear manner and allowed conclusions to be categorically drawn (Schulze et al., 2016). The results of the mapping study provide an overview of the research area; illustrate what research evidence exists and quantify the amount of such evidence (Yli-Huumo et al., 2016). To guarantee the quality of the results, a precise and rigorous methodology for conducting the review process had to be used. This consists of three main phases; planning, conducting and reporting on the review (Zavala et al., 2018), Figure 1. The planning phase defines all the relevant decisions for the study, ensuring a documented structure is in place before commencing the work. The conducting phase implements the planned process and structure while recording information throughout each iteration or stage. The final stage, consists of reporting the results and findings allowing for further evaluation, discussions and conclusions to be drawn (Zavala et al., 2018).

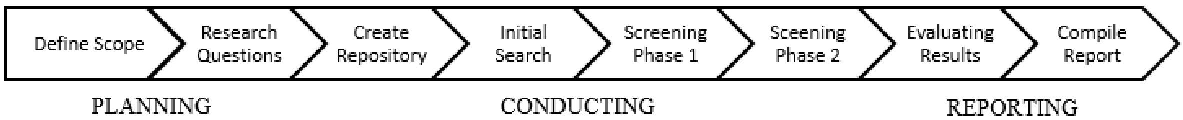

Figure 1. Phases of the Methodology.

2.1. Research Questions:

The objective of this paper was to gain a broad understanding of industrial smart and micro grid technologies and to systematically create a representative compilation of current literature on this topic. To ensure the reliability of the process this was completed in several distinct phases, as discussed. The first stage in the process, once the scope of the topic had been set, was to define the specific research questions, Table 1, used to focus the work throughout this paper. Each research question was selected to target a different aspect of the topic to comprehensively evaluate this subject matter. The first research question is designed to capture and evaluate the positive factors and advantages associated with the implementation and development of these technologies.

> *"What are the leading benefits associated with facility-wide smart grid networks, regarding renewable technologies and utility performance / optimisation?"*

The benefits of this technology will aid the determination of certain driving factors as well as potential for further advancements in this area. As part of this research it was interesting to assess the most common advantages of this technology as well as determining which stakeholders were most frequently benefitting from its operation.

The second research question is more focused on the negatives and potential difficulties faced in the development, implementation and utilisation of this technology;

> *"What are the most significant barriers to adoption of smart / micro grid technologies?"*

This was geared towards investigating and evaluating the most common pitfalls and negative factors slowing down the development or creating barriers to the utilisation of this technology. From a research perspective it was particularly interesting to assess the negative aspect of this area, since this not only furthered the understanding of the field but could potentially provide opportunities for further research into solving these problems. The intention was also to evaluate whether the barriers to development were based on technology limitations, stakeholder reluctance or legislation influenced among other potential reasons.

The third research question analyses the geographical distribution of research on this subject matter;

> *"Where is the majority of research being conducted and what are the clearest driving factors of this topic in these regions?"*

The intended outcome of this analysis is to determine which countries or regions are dominating the research in this area. Using these research trends, it is possible to delve deeper and evaluate potential driving factors as to why certain areas are more heavily focused on the topic. It is likely that national legislation and funding bodies may provide the strongest factor in countries contribution or lack thereof to this field. Possible outliers may exist from the expected trend which presents interesting points in further the understanding of this topic.

The fourth research question aims to assess how policies have influenced this technology, both in the past and into the future;

> *"How have industrial and governmental policies driven / affected the development and implementation of industrial smart / micro grids in the past and their potential in the future?"*

The objective of this question is to delve into how both governmental and industrial politics have affected the topic. This aims to improve the understanding of how the technology has been directed to where it is now. Possibly uncovering trends in its development or categorising whether it is policy leading or lagging. Further opportunities to uncover development directions for the future may be uncovered based on how the stakeholders may be affected by policy changes or coming updates.

The fifth and final research question was designed to quantify at what stage most of the work in this area is and how developed the current technologies are;

> *"How developed is this topic currently and at what stage are the majority of research and papers at this moment in time?"*

The focus of this is to determine whether the research topic is at an early or philosophical phase or much more advanced and approaching more evaluation focused work. This will help to define where present day research fits on the timeline for this subject matter. Outputs from this have the potential to present further development opportunities or knowledge gaps. As technologies in their early stages of development often follow meandering paths to maturity there are frequently great opportunities to gain valuable knowledge along the way.

Table 1
Research Questions of the paper.

	Research Question
RQ1.	What are the leading benefits associated with facility-wide smart grid networks, regarding renewable technologies and utility performance / optimisation?
RQ2.	What are the most significant barriers to adoption of smart / micro grid technologies?
RQ3.	Where is the majority of research being conducted and what are the clearest driving factors of this topic in these regions?
RQ4.	How have industrial and governmental policies driven / affected the development and implementation of industrial smart / micro grids in the past and their potential in the future?
RQ5.	How developed is this topic currently and at what stage are the majority of research and papers at this moment in time?

2.2. Creating the Repository:

Creating an all-encompassing and well-defined research paper repository was key to the success of this research. With this in mind, conducting some initial research to familiarise oneself with the topic was invaluable. After taking this short time to delve into the subject matter it was possible to identify the keywords and case specific requirements of this research area. Using the additional information gathered a database structure was tailored to the key aspects and intricacies of the topic. The chosen headings provide the best selection of metadata and information to describe the qualifying papers and answer the research questions. It was decided to use Microsoft Excel to compile the research papers into a spreadsheet. As this provided a uniform, accessible and easily organised platform to store and analyse the collected research papers.

2.3. Initial Search:

The next stage was to search for papers in the specific research area. From the early stage information gathering it was decided that the papers would be sourced from a combination of four relevant peer-reviewed databases; IEEE Xplore, Science Direct, Scopus and Google Scholar (O'Donovan et al., 2015). Other sources were considered, like the ACM Digital Library and Engineering Village, but were ultimately determined surplus to requirements. This was largely due to a significant cross-over in papers between Elsevier databases, a lack of relevance in database description and scope and unavailability of full access at that time, leading to the additional databases being excluded from the search list.

Each of the four selected databases had their own unique search methods, from basic single-entry search engines to more advanced procedures allowing for more advanced search criteria specifications. Using the search terms shown in Table 2, a variety of papers were uncovered that would form the basis of the research paper repository. As seen in Table 2, within each search engine a variety of different search areas were used, from "Document Title" only to "Full Text". Maintaining a broad search area as well as varying the search terms, for example including smart grid or micro grid and using the quotations to ensure the whole word combination was searched for, drastically helped to compile a comprehensive research paper repository.

Table 2
Search String terms.

	Database	Search Area	Search Terms			*Filters*
1	IEEE Explore	Document Title	Industrial Smart Grid	OR	Industrial Micro Grid	Conferences
2	IEEE Explore	Metadata Only	"Industrial Smart Grid"	OR	"Industrial Micro Grid"	
3	Science Direct	Full Text	"Industrial Smart Grid"	OR	"Industrial Micro Grid"	
4	Science Direct	Title	Industrial Smart Grid	OR	industrial microgrid	
5	Scopus	All Fields	"Industrial Smart Grid"	OR	"Industrial Micro Grid"	
6	Scopus	Title-Abstract-Keywords	Industrial Smart Grid	OR	Industrial Micro Grid	Conference Papers (cp)
7	Google Scholar	Exact phrase, anywhere in the article, not including patents or citations	"Industrial Smart Grid"			
8	Google Scholar	Exact phrase, anywhere in the article, not including patents or citations	"Industrial Micro Grid"			

2.4. Screening Phase 1:

Once the search was completed and the relevant papers compiled, an initial screening phase was required to eliminate certain non-qualifying papers. At this phase only relevant, peer-reviewed papers written in English and available in full text were passed through to the next phase. The qualifying papers and their metadata were then tabulated within the repository under the predetermined headings. For this phase the title and abstract of each paper was reviewed to determine its relevance. Any disqualified papers at this phase had their relevant metadata recorded and compiled on a separate sheet in Excel along with a brief reason for their exclusion. This screening helped to further focus and reduce the number of papers within the repository, Figure 2.

2.5. Screening Phase 2:

The final phase of screening was more focused on the output of the papers, by again reading the title and abstract as well as the results/conclusion sections. This more in-depth analysis of the research papers presented the opportunity to further categorise the qualifying papers. From this screening each paper was categorised by data source, data type, whether its results were qualitative or quantitative, its research classification and what stage the research presented was at. The data source category aimed to define whether the paper originated from academia or industry. Determining the percentage share of papers from each would help to illustrate where the driving factors are coming from and how much influence either sector has on the topic. The data source was used to clarify whether the paper was presenting primary or secondary data. This was valuable to see if there was a majority of papers presenting original research from direct sources and results or review and summary papers of existing data. Analysing whether the papers were more qualitative or quantitative offered the opportunity to categorise the papers based on their presented results. Overall each paper was reviewed to establish whether its output was more speculative, opinion based and review oriented or defined, quantifiable and presenting heavily numerically based results. The research classification then allowed the relative maturity of the papers within the repository to be visualised. Categorising each paper as either philosophical, solution or evaluation (Donovan et al., n.d.) allowed the phase of research to be quantified and illustrated clearly. Similarly, to the research classification the research stage section further developed the depiction of the maturity of the papers. By classifying the papers under initial phase, middle phase and final phase it is possible to clearly identify how early or advanced the research presented within is.

These additional headings were very beneficial in evaluating the papers within the research paper repository and helping to understand and display the state of this subject matter. As with the previous screening stage any non-qualifying papers, accompanied by a brief explanation, were excluded and stored on a separate sheet within the Excel file, Figure 2.

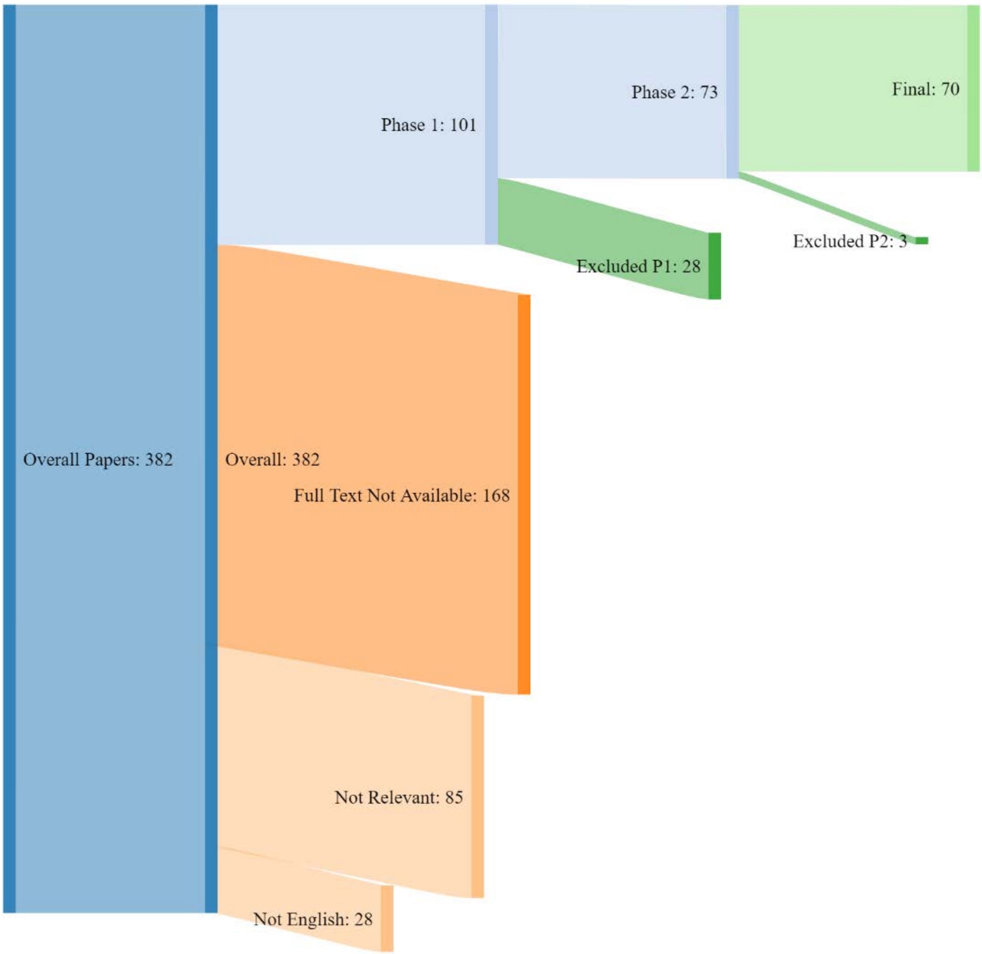

Figure 2. Elimination of Papers throughout the Screening Process. (Bogart, n.d.)

3. Results:

3.1. Descriptive Analysis:

3.1.1. Year of Publications:

By analysing the previously identified body of literature and extracting the publication date of each paper it was possible to track the evolution of the topic of each of the 70 papers reaching the final stage. Figure 3 illustrates the development of research in this area over time, beginning with the single recorded paper in 2010 to the 10 papers published at the time of the study in 2018. From this graphic it is clear that interest in this area is growing consistently year upon year. The incomplete 2018 figure being the only year not to outperform its predecessor remains on course to continue the trend, as shown by the dashed line in Figure 3. Research into this topic is quickly gaining momentum demonstrating its value but also proving there are knowledge gaps present worth exploiting. With the first paper appearing in only 2010 the subject is relatively new but if the displayed growth continues it is likely to rapidly reach maturity.

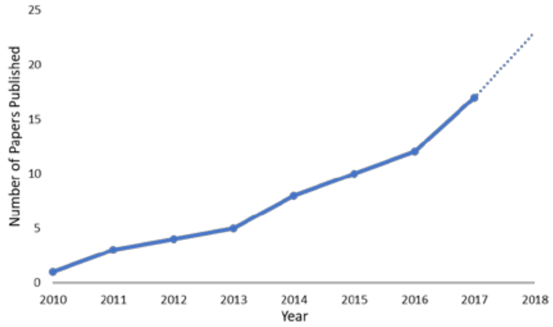

Figure 3. Number of Publications per Year.

3.1.2. Geographical Distribution:

Figure 4 displays the number of papers published per country of the final 70 research papers. The widespread distribution shows global interest in the topic compounding the belief that this is a valuable emerging topic. China and Germany appear as research publication leaders in this area with 13 and 9 papers published respectively. But significant contributions can also be seen from Iran, the USA, Italy and the United Kingdom. According to the Nature Index the USA, China and Germany would be expected to lead statistics here as they are the top three countries for research outputs (Limited, 2018). This further highlights the significance of the number of outputs coming from Iran, which is much further down on this list (Limited, 2018). From this table it is also clear that Europe and Asia are the dominant continents regarding papers published, with 31 and 28 papers respectively making up almost 85% of the final repository.

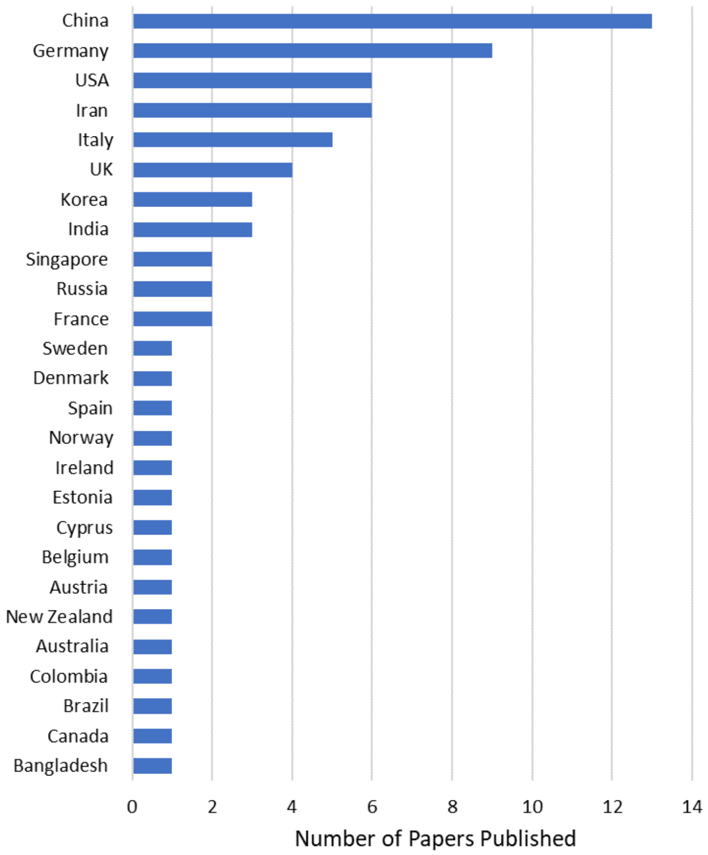

Figure 4. Papers published per Country.

3.1.3. Research Source:

The papers in this area demonstrated a relatively even mixture of sources. The final papers were divided into 56% conference papers and 44% journal papers, as shown in Figure 5. The research contribution from academia compared to industry was far more one sided, as seen in Figure 6. Academia accounted for 83% of the papers published compared to the 17% which had an industry focused source.

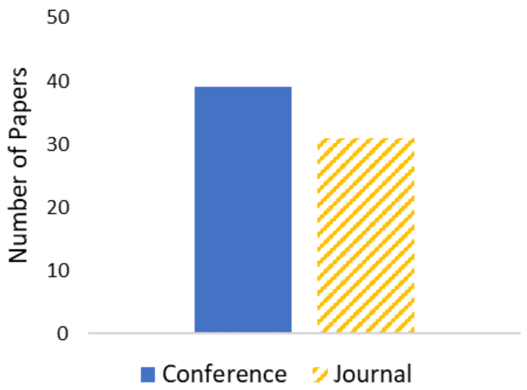

Figure 5. Publications per Source.

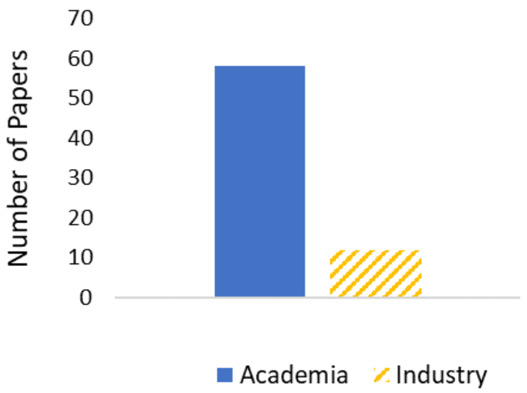

Figure 6. Publications per Source.

3.1.4. Data Type:

The assessed papers within the repository presented a mixture of data types. Figure 7 highlights the difference between papers providing primary and secondary data. With 67% of them presenting primary data or findings and the remaining 33% providing secondary data. Another interesting metric was the comparison of papers presenting qualitative or quantitative data, Figure 8. There was a clear sway towards qualitative outputs as shown by the 74% of papers supporting this statement. The remaining 26% of papers offering quantitative results were significantly in the minority in this case.

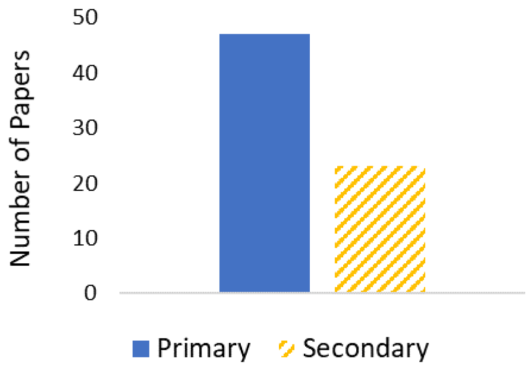

Figure 7. Classification of Data.

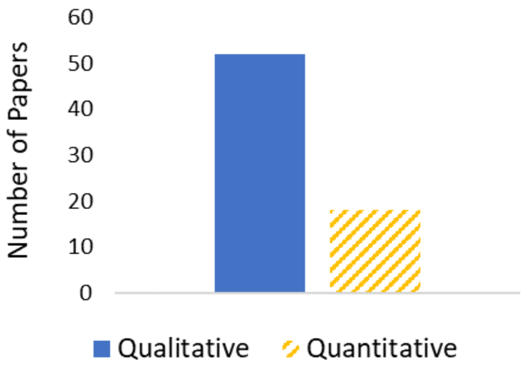

Figure 8. Classification of Data.

3.1.5. Research Classification:

Within the repository there were a variety of papers at each stage of maturity from philosophical to solution to evaluation, as shown in Figure 9. There is a clear dominance in the earlier phases with 36% and 57% of papers classified as philosophical and solution respectively compared to only the remaining 7% papers falling into the evaluation category.

This is an indicator of the maturity of the topic and how the research foundations must be laid before evaluations and case studies can be conducted.

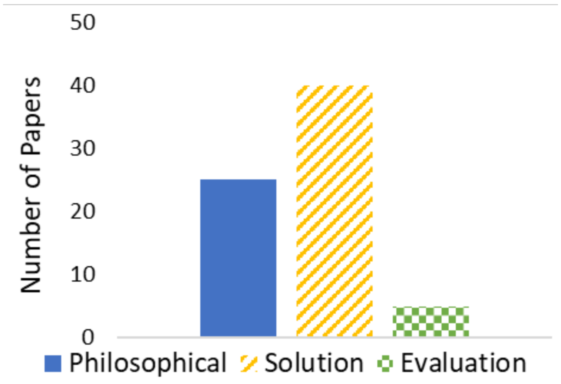

Figure 9. Classification of Papers.

4. Discussion:

4.1. Research Question 1:

By conducting a comprehensive review of the current literature and existing technologies in this area it was possible to evaluate the topic and present specific findings. One recurring benefit of these systems is the ability to further integrate RESs and DERs into functioning electricity grid systems, Figure 10. A substantial difficulty associated with renewables is their unpredictability and lack of stability. The significant fluctuation in generation from wind and solar photovoltaics being prime examples (Nosratabadi et al., 2017). Using Demand Response methods this technology is capable of adding additional control aspects and balancing these energy sources to benefit the systems network. This was particularly evident during a case study evaluating the reliability parameters of a micro grid operating in such a way (Nosratabadi et al., 2017).

Further advantages are displayed with the incorporation of ESSs providing additional assistance and benefit to the network. Frequency response, load shifting and demand curve smoothing are examples of the benefits of an optimized ESS incorporated within a smart grid system (Xie et al., 2017). Throughout the literature these valuable assets continually prove their worth to industrial energy networks, displaying improved stability and confidence in the smart grid system (Samad and Kiliccote, 2012)(Xu et al., 2018).

Security of supply frequently appears in publications and stands out as another crucial advantage of smart grid systems to the industrial sector, Figure 10. With current aging electricity grid infrastructure coming under increased pressure from the rapidly evolving electricity network (EirGrid and SoNi, 2014), more and more industries are moving towards securing their own supply. This is often in the form of one or a combination of multiple RESs and DERs on site providing energy for their facility (Blake and O’Sullivan, 2018). This on-site generation capability allows industries to remain operational in the case of grid outages or during times of exceptional network strain (Samad and Kiliccote, 2012). While offering further benefits with the added potential to operate in islanded mode and eliminate the need for a grid connection altogether where appropriate (Misaghian et al., 2018)(Blake and O’Sullivan, 2018)(Xie et al., 2017).

The added benefit of increasing renewable energy generation on site is the inherent reduction of greenhouse gas emissions (Zhang et al., 2018). Smart grid systems allow industrial networks to further integrate cleaner energy production and so reduce their dependence on a fossil fuel heavy national grid or localised fossil fuel generators (Samad and Kiliccote, 2012). This characteristic is particularly beneficial when it comes to complying with national and international legislations and meeting energy performance targets. For an industry, minimising carbon emissions can drastically improve their Corporate Social Responsibility ratings, provide a competitive edge and reduce the likelihood of failing performance targets and incurring fines or increased carbon taxes (N. Yu et al., 2016).

One significant advantage in the vastly competitive industrial sector are the financial gains achievable with this technology, Figure 10. Not only from the avoidance of emission and environmental taxes as discussed, but the reduction in utility bills from cheaper production and asset optimization (Samad and Kiliccote, 2012). Industrial sites can avail of sophisticated demand response mechanisms to optimize their facility and make monetary savings from efficient consumption scheduling, load shifting and various other ancillary services provided by an effectively run smart grid system (M. Yu et al., 2016). Continued advancements in micro grid management systems offer further potential to optimize energy performance, maximise the impact of RESs and minimise the energy cost, carbon dioxide and pollutant emissions, further providing financial savings (Elsied et al., 2016).

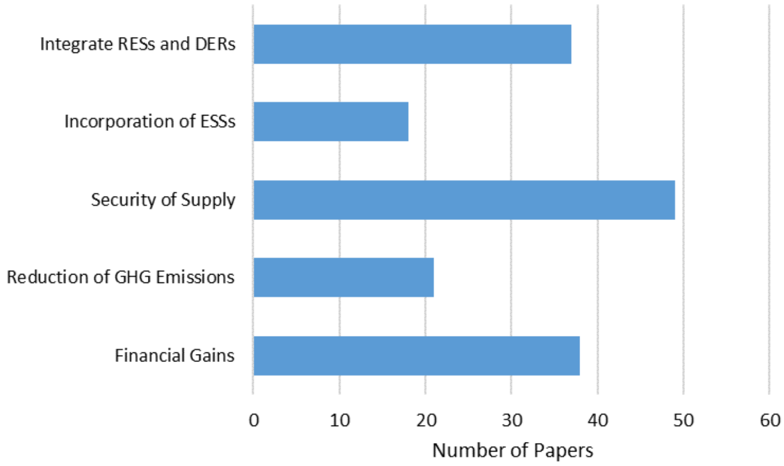

Figure 10. Number of papers per Research Question 1 key points.

4.2. Research Question 2:

With all developments and technological advancements there can be certain reservations and barriers to adoption. Industrial smart and micro grid systems are no different in this regard, with early phase adoption slowed for various reasons (Ma et al., 2015). A lack of clarity and definition contributed to some stakeholders harbouring reservations to implementing this technology. A survey conducted of representative stakeholders in Norway confirmed this statement as well as indicating that at the time there was no accepted definition of the meaning of “Smart Grid” (Oyetoyan et al., 2012). For emerging technological advancements lack of understanding and clarity can significantly hinder progress and drastically slow down implementation.

Another potential drawback for this innovation which features heavily in the literature is the lack of existing infrastructure, Figure 11. Namely advanced sensors, monitoring and metering equipment capable of communicating vast quantities of information rapidly between servers to adequately control and operate the system (Ancillotti et al., 2013)(Teive et al., 2015). Traditional electric power systems are becoming more and more outdated and the retrofitting of required infrastructures and equipment can accumulate high costs to the stakeholders. Additional costs accrue when companies are forced to develop bespoke systems to cope with unique and site specific issues (Teive et al., 2015).

A major barrier to this technology is the growing necessity for cyber security strategies (Oyetoyan et al., 2012). Although there are only a few papers currently published on this topic, Figure 11, as the implementation and scale of this technology increases so too does the importance of adequate security measures. The volume of information from meters and consumers required to be stored and analysed will continually grow in turn leading to the cyber security systems becoming increasingly strained. As this technology is currently at an early phase it is likely that with further development and more case studies appearing this area will be highlighted more and more. Continual development and improvement of privacy and security strategies will be necessary to sustain the implementation and growth of smart and micro grid networks. To achieve this, regulations and standards of practice will have to be defined and implemented to ensure cyber security is controlled and maintained to the highest standard (Henneke et al., 2018). Many potential roadblocks and barriers to deployment may appear as significant influence and involvement of governments and regulatory bodies is required to achieve this high grade of security systems management (Oyetoyan et al., 2012).

With all innovations progress is often impeded by a lack of hardware technologies and capabilities. The electric grid is no different and so the rate of advancements in certain devices can be intrinsically linked to the pace of smart grid developments, Figure 11. One example of this is the impact of power semiconductor devices and their rate of improvement in areas such as increased voltage, frequency and temperature limits (Huang, 2017). Availability of adequate control systems has also impacted the widespread implementation of high-grade smart grid systems. Before the emergence of cloud-based applications and the necessary infrastructure to connect controllable local systems to external entities it was much more difficult to control and operate micro grid systems (Henneke et al., 2018).

The higher capital costs of smart grid systems architecture and infrastructure is another barrier too its adoption. The various additional costs of equipment, operating and security systems mentioned often discourage commitment and participation from industry. The adoption of such new behaviours and priorities is often slow in industrial settings, as eluded too in certain case studies (Ma et al., 2015). Additionally the apparent perception of unprofitability can hinder organisations evaluation of opportunities, with a specific impact being found on the incorporation of ESSs into certain networks (Halstrup and Schriever, 2018). As a result, the financial aspect of smart and micro grid systems is clearly one of the barriers to its adoption, development and implementation.

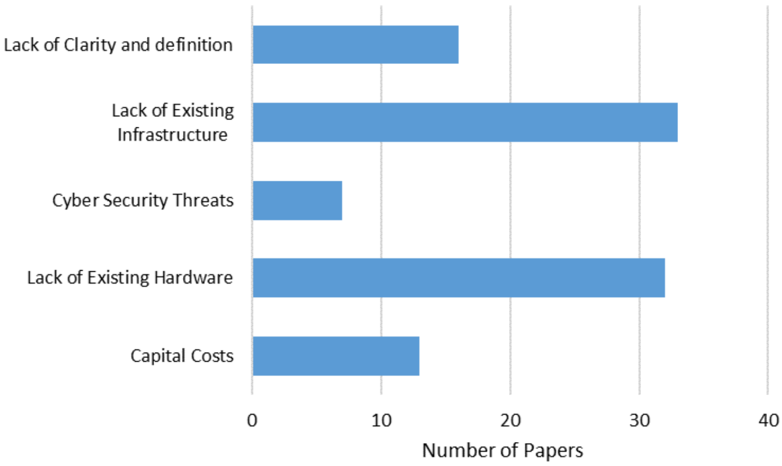

Figure 11. Number of papers per Research Question 2 key points.

4.3. Research Question 3:

The majority of research being conducted and published in this area originates from developed or rapidly developing countries, as seen in Figure 4 and Figure 12. Of these contributors China is the stand-out country with 13 publications, the most on the topic in the compilation. Germany is a not too distant second with 9 papers and the USA and Iran follow with 6 publications each. Research is being conducted relatively evenly across the northern hemisphere, with the common powerhouses of the European Union, Asian and American economies leading the way. Interestingly, each of the 4 countries mentioned as leaders in research publications are listed in the top 10 by the EDGAR for CO_2 emissions in 2016 (European Commission, 2017). China is top of this chart as well, followed by the USA in 2nd, Germany in 6th and Iran in 8th place (European Commission, 2017). Each countries performance here is likely to have influenced certain decision-makers to push policies and incentives in their regions favouring the adoption of industrial smart and micro grid systems.

Another significant event causing a surge in publications for each of these regions was the Paris Agreement in 2015 and signing of Nationally Determined Contributions (NDCs) in 2016 (United Nations Framework Convention on Climate Change, 2018). Iran was the only country of the 4 mentioned not to officially sign an NDC at the time, although the USA have since moved into a grey area, it was still important in bringing matters like this topic to the fore on an international scale. A significant driving factor for this subject matter is the direct reference and commitment in the Chinese NDC document;

> *"To scale up distributed energy and strengthen the construction of smart grid."* (Department of Climate Change, 2015)

Each of the countries NDC submissions specifically referenced industrial processes and energy use, further driving research and implementation of this technology within their respective regions.

Importantly for the topic there is a decent combination of both developed and developing countries. Germany being a significant part of the European Union and the USA both being ranked as developed countries by the United Nations (United Nations Department of Economic and Social Affairs (UN/DESA), United Nations Conference on Trade and

Development (UNCTAD), Economic Commission for Africa (ECA), Economic Commission for Europe (ECE) et al., 2018) are typically best placed to invest in emerging technologies. The strength of their economies often allows more funding to be allocated to research and development as well as maintaining pace in development races across the board. Both of these countries maintain steady rates of growth of real GDP throughout the years of research and publications in this area (United Nations Department of Economic and Social Affairs (UN/DESA), United Nations Conference on Trade and Development (UNCTAD), Economic Commission for Africa (ECA), Economic Commission for Europe (ECE) et al., 2018). Further compounding the value of governmental investment and policies driving research and development in the area. As both China and Iran are categorised as developing countries (United Nations Department of Economic and Social Affairs (UN/DESA), United Nations Conference on Trade and Development (UNCTAD), Economic Commission for Africa (ECA), Economic Commission for Europe (ECE) et al., 2018), it is encouraging for this topic to see them contributing so strongly. China specifically is currently in the process of rapid industrialization and urbanisation (Department of Climate Change, 2015) and so the development and implementation of this technology throughout a growing phase for this nation illustrates its importance and associated value. Interestingly for both of these countries their publications also come at times of strong rates of growth of real GDP (United Nations Department of Economic and Social Affairs (UN/DESA), United Nations Conference on Trade and Development (UNCTAD), Economic Commission for Africa (ECA), Economic Commission for Europe (ECE) et al., 2018). This is likely to have influenced the investment and governmental provision of resources and policies to push research and developments on the topic.

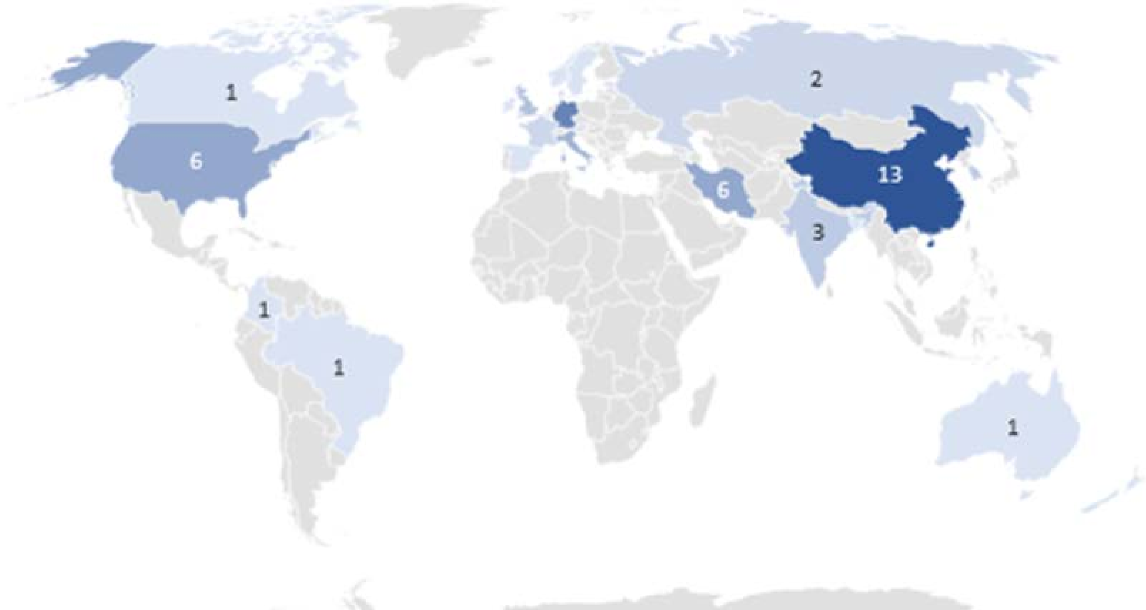

Figure 12. Heat map of papers published per country.

4.4. Research Question 4:

Governmental legislations and emissions targets have and will continue to have a large impact this topic. Since the industrial sector has such an influence on national emissions performance, up to 30% in some cases (Choobineh and Mohagheghi, 2016), significant pressure will be put on these decision makers to reduce their impact and tie in with national energy and emissions targets (SEAI, 2016). This is certainly the case in Ireland with industrial facilities adapting and incorporating this technology with the goal of maximising their energy efficiency, emission control and use of RESs (Blake and O'Sullivan, 2018). This example is certainly not an outlier as there have been more and more cases across the world to reinforce the global recognition of the need for a change in the electric power systems (Ma et al., 2015). The Paris Agreement has further pushed governments into stricter emissions and energy efficiency targets which this technology will help to achieve and maintain.

Clean transport is growing in significance and so electric vehicles are becoming a key factor as policies and financial incentives in this area have driven their adoption (Panwar et al., 2015). Industries are also being incentivised to incorporate these elements into their site portfolios, thus requiring existing electricity infrastructure to adapt and cope with the issues introduced by these technologies (Bessler et al., 2018). Further developments into smart frequency control and effective voltage regulation among other things are needed to combat the adverse effects of significant electric vehicle charging and use within an industrial electricity grid (Panwar et al., 2015). The continual increase in electric vehicle numbers will play a part in the research and development of industrial smart and micro grid systems especially with the continuation of strong governmental policies and incentives behind them. Although there are relatively few papers currently published in this specific area, Figure 13. It is clear from what is out there that as electric vehicle adoption rises and more charge points are installed on smart grid networks, research and development will be required to seamlessly accommodate them.

With most innovations and developments, a decisive factor for their continuation can be whether they are financially backed or supported by industries or government groups. This topic is no different, Figure 13, so the commitment from the German government for example shows that its development will be assisted in the future. Projects like the POLAR project, funded by the German Federal Ministry of Education and Research (Maasem, C.; Roscher, M.; Braun, 2014) and the DC-INDUSTRIE research project, also funded by the German government (Schaab et al., 2018), demonstrate the importance of governmental policies and financial backing for this topic.

Concerns about the reliability of the existing electrical grid as policies encourage utilization of more and more fluctuating energy supplies like RESs and DERs have also impacted the necessity for a solution like industrial smart and micro grid systems (Xenos et al., 2016). Industrial energy users with sensitive processes may have concerns over the growing demand, increased generation of fluctuating supply from wind and solar and the decreasing proportion of stable power generation sources within the national electricity grid networks (Xenos et al., 2016). This has clearly added further incentive for them to endeavour to introduce their own energy supply on-site and implement a management system which they can control themselves, Figure 13. This is particularly relevant in large industries where having their own controllable supply allows them to define the standards and strive for class leading performance and the highest level of operation (Schaab et al., 2018).

Over time the energy performance and emissions policies will become stricter and industries will be forced to maintain continual improvements. These polices may be challenging but they will force industries to innovate and search for new solutions and ways to optimize their existing technologies. Studies have already been conducted for cases just like this with a view to maximising the potential of existing assets (Eseye et al., 2016). Aside from achieving compliance with regulations, industries will always look to optimize the cost effectiveness of their assets and operation. Smart grid systems offer the potential to provide lucrative services like demand response and load shifting to the national grid as well as internal energy management and operational cost reductions for the industrial facility (Logenthiran et al., 2011).

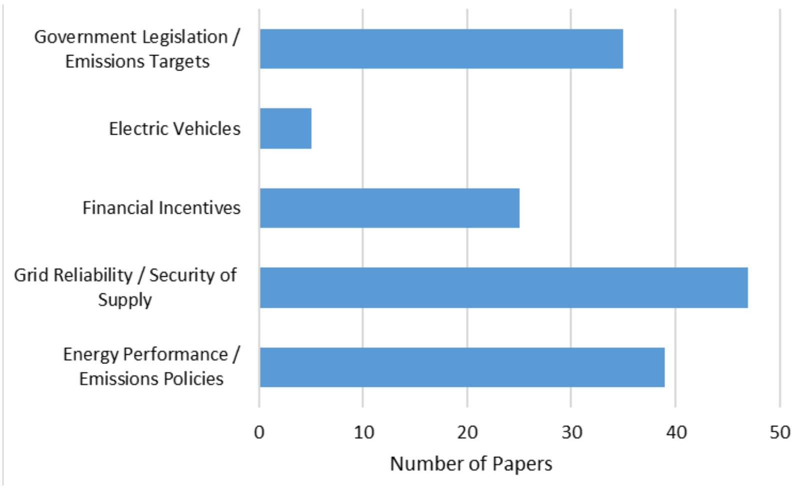

Figure 13. Number of papers per Research Question 4 key points.

4.5. Research Question 5:

The findings of this study show that the smart and micro grids are still emerging technologies. The majority of the research is at an early stage demonstrating the fact that this is a developing topic. As seen in Figure 14, the majority of the papers, 96%, are concentrated in the initial or middle phase. This illustrates the point that the topic is only beginning to be studied and there will be plenty of opportunities to mature the topic and exploit all of the uncovered knowledge gaps. Further emphasis of this point is present in the evaluation of the middle stage research. Over 80% of papers outline the framework for full studies, simulations and possibilities or discuss potential case studies and opportunities to further the area before the work has been completed (Oyetoyan et al., 2012)(Jia et al., 2015)(Gamarra et al., 2016).

The same conclusion can be drawn from the evaluation of research in terms of philosophical, solution or evaluation paper contributions shown in Figure 9. This again highlights the early development phase of research in this topic, with the majority of papers skewed towards the early phase. Even further reinforcement of this point is shown by many of the solution papers being highly speculative and lacking substantial data. The absence of significant amounts of case studies also demonstrates the immaturity of the topic. Many of the papers present the potential for case studies or use existing facilities to speculate or simulate the effect of introducing theoretical systems in the future (Schaab et al., 2018)(Zhou et al., 2014)(Beldjajev and Lehtla, 2010).

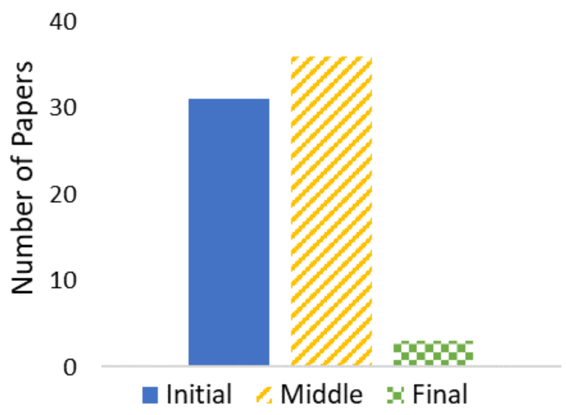

Figure 14. Classification of papers.

5. Conclusions:

This paper presents a systematic mapping study on industrial smart and micro grid systems. The work aims to give a comprehensive overview of the current state of the art and the significant factors shaping the landscape of this subject matter. The study follows the defined and structured layout of a systematic mapping study and incorporates the knowledge and information from the 70 research papers selected by this process. The aim of each chosen research question was to target a specific area, with each individual result combining to paint a comprehensive picture of the topic. In this way the benefits and potential barriers of this technology are thoroughly evaluated. Where much of the research is being conducted and why this may be the case. From this the policies and driving factors for this research are explored and finally the maturity of the topic itself is evaluated, illustrating knowledge gaps and potential areas for future work.

A recurring consensus from the literature is that this topic is still at an early phase, but it is maturing quickly. This is largely aided by backing from governments of economically stable and profitably developing countries as well as industries eager to benefit from the financial gains and security of supply, reducing their reliance on an electricity grid that is struggling to adapt to modern day requirements. Another universal benefit of this technology shown in the literature is its ability to further incorporate and maximise the use of renewables and cleaner production methods. The harmonisation of additional RESs into the electricity generation pool and optimisation of existing assets will further help to reduce the use of fossil fuels and cut harmful emissions across the world. This technology is generally presented in a positive light, with the many benefits outweighing the potential drawbacks such as high capital costs of lack of infrastructure. These barriers are highlighted more as knowledge gaps and areas for significant research and development to further improve the subject matter.

6. Next Steps:

This technology will continue to develop and grow into the future. As a result, there are many different areas for future work that will help to improve and further this topic namely;

- Incorporating ESSs into an existing system to further optimise asset and financial performance as well as improve grid resilience, reliability and controllability. This appears as a knowledge gap in the current literature as there are comparatively very few papers in this area, Figure 10.

- The effect of Electric Vehicles and their charging points is set to grow as industries are continually incentivised to incorporate them into their portfolios, Figure 13. The ability of electricity grids to cope with frequency fluctuations and varying demand curves offers huge research potential.
- Cyber Security Threats, Figure 11, are also likely to become more pertinent as this technology becomes more widespread. With the increased amount of information being collected and stored, newer and more robust security strategies will have to be developed to stay ahead of any potential threats.
- Future policies and industrial standards are likely to have a large impact on the implementation of this technology now and in the future. As such, it may be worth investigating the development and utilisation of these documents and assessing their effect on industries.

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