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Research paper

A framework for selecting the location of very large photovoltaic solar power plants on a global/supergrid

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ABSTRACT

One of the important optimization applications (minimization and maximization) is the power grid systems. National electricity grids should be interconnected to develop larger regional grids (supergrids), and further integrated to build up a worldwide grid (global grid) for minimizing consumption of natural resources and maximizing economical useful life, recycling rate, and effective usage of natural resources. These supergrids and global grid concepts can only be developed through detailed and organized supportive research studies. This research study aims to find, define, identify, describe and select location selection factors of very large photovoltaic solar power plant investments on a global grid and supergrid concepts. Grey systems theory, fuzzy (Type-1 and 2) theories, Mamdani's type fuzzy rule-based system, Interpretive Structural Modelling (ISM), Impact Matrix Cross-Reference Multiplication Applied to a Classification (MICMAC) tool, and Political, Economic, Social and Technological (PEST) framework and its extensions (SLEPT, PESTEL, PESTLE, STEEPLE, STEEPLED, DESTEP, STEER) are concurrently used in this study. Eleven (11) criteria are presented for preliminary screening (i.e. C_1: global horizontal irradiation (GHI), C_2: governments supergrid integration policy, C_3: supergrid business climate and conditions, C_4: High Voltage Direct Current (HVDC) and High Voltage Alternating Current (HVAC) electrification grid infrastructure, C_5: land use, allocation and availability, C_6: geological conditions, C_7: political, war, terror & security, C_8: topographical conditions, C_9: climatic conditions, C_{10}: water availability conditions, C_{11}: natural disaster/hazard conditions), and 191 factors are presented for pre-feasibility investment stages. Findings can directly be used or taken as a basis for further analysis by researchers and practitioners.

1. Introduction

Electricity is very vital to our modern daily life, because of its utilization in almost everything. Extending electricity to cover several regions of the World is therefore necessary, because of continuous and increasing demand that is associated with population growth (see IEA (International Energy Agency), 2014). Apart from the escalating population, research, development and innovations in new environmentally sound products (e.g. electric vehicles) have also increased electricity demand. Hence, increase in electricity supply is very necessary.

According to the International Energy Agency (IEA), the total energy demand is expected to increase by 32% between 2012 and 2035. With this, the utilization of renewable energy (RE) sources (hydropower, geothermal, wind, solar, ocean etc.) are expected to increase by 73% in the same period, while non-renewable energy sources are expected to have run out in the future (IEA (International Energy Agency), 2014; Hirsch, 2008; Jakobsson et al., 2009; Lloyd and Forest, 2010). A transition period of a 100% RE power grid adoption is thus expected in 40 to 120 years (Kuhlman, 0000; Hussain, 0000). An important RE source widely available is the Sun (solar energy). Electricity generation from solar photovoltaics (PV) technology, has remarkably increased since 1996 (Hussain, 0000); this is due to the technological breakthroughs, that brought about the declining cost associated with PV systems. Costs associated

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Table 1
Intention announced VLPVPPs until 2015.

Project title	Installed capacity (MW_p)	Country	Stage[a]	Reference
Helios	$3000 \leq P \leq 10{,}000$	Greece	IA	ProjectHELIOS (2014)
Ladakh	$P = 7500$	India	IA	Times Of India (2015)
Westlands Solar Park	$P = 2400$	USA	IA	Westlands Solar Park (2014)
Bulli Creek	$P = 2000$	Australia	IA	CleanTechnica (2015)
Ordos Solar	$P = 2000$	China	IA	GreenEnergyReporter (2014)
Kargil	$P = 1000$	India	IA	SECI (2015)
Mohammed bin Rashid Al Maktoum Solar Park	$P = 1000$	United Arab Emirates	IA	DEWA (Dubai Electricity and Water Authority) (2014)
Quaid-E-Azam Solar Park	$P = 1000$	Pakistan	IA	QASOLAR (Quaid-e-Azam Solar Power) (2014)

[a]IA = Intention Announced.

with PV systems can be further minimized through the advantage of economies of scale, via the design of very large PV power plants.

In this study, very large photovoltaic power plants (VLPVPPs) are considered as power plants having installed capacity that is equal to or above 1000 MW_p (p = peak). Operational VLPVPP is currently non-existent worldwide, although some projects are under considerations (see Table 1) (ProjectHELIOS, 2014; Westlands Solar Park, 2014; GreenEnergyReporter, 2014; DEWA (Dubai Electricity and Water Authority), 2014; QASOLAR (Quaid-e-Azam Solar Power), 2014; Times Of India, 2015; CleanTechnica, 2015; SECI, 2015).

Cumulative capacities are considered over 3000 MW_p in Europe (Greece), 12,500 MW_p in Asia (China, India, Pakistan and the United Arab Emirates), 2400 MW_p in North America (USA), and 2000 MW_p in Australia, giving a total capacity over 19,900 MW_p worldwide. It is thus very clear that VLPVPPs shall catalyze the adoption of global grid and supergrids in the near future. European Supergrid (Elliott, 2010; Friends of the Supergrid, 2012), Supergrid Concept for America (Overbye et al., 2002), DESERTEC (DESERTEC Foundation, 2013), Gobitec and Asian Super Grid (Mano et al., 2014; Seliger and Kim, 2009), and Global grid (Chatzivasileiadis et al., 2013) are some of these futuristic concepts. Hence, finding, selecting, presenting and investigating the most appropriate VLPVPPs locations will be very beneficial for governments, organizations and investors etc. in understanding the technical and financial viability of specific VLPVPP sites for global grid and supergrids. Site selection of a VLPVPP depends on location selection factors (criteria); hence, perfectly defined, identified and selected location selection factors are obligatory. In this respect, this study is focused on finding, selecting, defining and identifying the most suitable location selection factors for new VLPVPP investments (location/site specific), needed for global grid and supergrids, using a generic decision support methodology (1st generation Original Anatolian Honeybees' Investment Decision Support Methodology, Location Selection Factors Module: 1GOAHIDSM), that is under its *research, development, demonstration, deployment, and diffusion* (RD^3&D) stage (see Saracoglu, 2016b).

Main contributions and originalities of this research paper are its: (i) presentation of 11 location selection criteria for preliminary screening stage of VLPVPP investments, and the adoption of 191 location selection criteria for pre-feasibility investment stage of VLPVPP investments, (ii) presentation of majors progress in RD^3&D of 1GOAHIDSM, (iii) presentation of a very deep document collection for literature review, a well-organized impression article collection and questionnaire survey, (iv) presentation of the first application (a sort of experiment for continuous improvements during RD^3&D) type-2 Mamdani fuzzy rule based system (fuzzy inference system: FIS) based on decision makers' preferences in this subject; this is planned to evolve to an automatic selection process based on worldwide files, (v) presentation of simple factors clustering approach, (vi) presentation of complex factors clustering by Grey Interpretive Structural Modelling (ISM), Impact Matrix Cross-Reference Multiplication Applied to a Classification (MICMAC) on Political, Economic, Social and Technological (PEST) framework, and (vii) extensions (a sort of experiment for continuous improvements during RD^3&D), that is planned to evolve to an automatic clustering process.

This paper consists of five sections. The second section presents literature review. The third section presents the application of methods in 1GOAHIDSM. Location selection factors for new VLPVPPs in global grid and supergrids are explained in the fourth section. Finally, concluding remarks and further research are discussed.

Table 2
Literature review procedure.

Step	Description
1	Identify keywords for searching on scientific online database & journal websites (KT1: very large photovoltaic solar power plant investments in the supergrid and the globalgrid concepts; KT2: very large photovoltaic solar power plants in the supergrid and the globalgrid concepts; KT3: very large photovoltaic solar power plant; KT4: very large scale photovoltaic; KT5: very large-scale PV; KT6: large photovoltaic power plant; KT7: large scale photovoltaic; KT8: large scale PV; KT9: photovoltaic power plant; KT10: VLS-PV; KT11: very large scale photovoltaic systems)
2	Search selected keywords on scientific online database & journal websites and additionally on search engines (i.e. ACM Digital Library: ACMDL, ASCE Online Research Library: ASCEOR, American Society of Mechanical Engineers: ASME, Cambridge Journals Online: CJO, Directory of Open Access Journals: DOAJ, Emerald Insight: EI, International Journal of Industrial Engineering Theory, Applications and Practice: IJIETAP, Journal of Industrial Engineering and Management: JIEM, Science Direct: SD, Taylor & Francis Online/Journals: TFJ, Wiley-Blackwell/Wiley Online Library: WB, World Scientific Publishing: WSP, www.baidu.com Baidu: SE1, www.bing.com Bing: SE2, www.dogpile.com Dogpile SE3, http://msxml.excite.com Excite: SE4, www.goodsearch.com Goodsearch: SE5, www.google.com Google: SE6, www.hotbot.com Hotbot: SE7, www.lycos.com Lycos: SE8, www.naver.com Naver: SE9, www.sogou.com Sogou: SE10, www.webcrawler.com Webcrawler: SE11, www.yahoo.com Yahoo: SE12, www.yandex.com Yandex: SE13, www.newslookup.com Newslookup: SE14, www.magportal.com Magportal: SE15)
3	Investigate found documents (papers, book chapters etc.) by their title, abstract & keywords
4	Select studies for detailed investigation and review according to their relevancy to current subject & aim
5	Investigate the selected documents in detail
6	Summarize reviewed studies in detail in the current study

Note: KT: Key Term (s); SE: Search Engine (s).

2. Literature review

Previous researches were investigated as shown in Table 2. A comprehensive review was carried out on 12 well-known scientific publishers' websites. There were nine (9) specifically selected key terms (KT) (i.e. KT1 to KT9), that covered the scope of this study. Among the numerous documents available (i.e. 2047), only thirty-one documents were found to be related to this study (Fig. 1) (Adiyabat et al., 2006; Ahadi et al., 2014; Bin and Dichen, 2013; Boran et al., 2010; Brenna et al., 2012; Carrión et al., 2008;

Cooper and Sovacool, 2013; Ehara et al., 2012; Faiman, 2004; Han et al., 2013; Islam et al., 2014; Ito et al., 2008, 2002, 2010a, 2011; Komoto, 2007; Krupa, 2013; Kurokawa et al., 1997; Obara et al., 2014; Paatero and Lund, 2007; Phillips, 2013; Sánchez-Lozano et al., 2014, 2013; Solomon et al., 2010b,c,a; Uchiyama et al., 2013; Yang et al., 2011; Yokota and Kumano, 2013; Yuventi, 2013; Yuventi et al., 2013). These documents were studied in details and their relevance with this study was evaluated and presented (Table 3, Fig. 1). It was realized during literature search, that there is no study that aimed to find, select, define and identify the most suitable location selection factors for new VLPVPP investments in global grid and supergrids.

Further literature work was done by considering the Photovoltaic Power Systems Programme of the International Energy Agency (http://www.iea-pvps.org), and specifically, the Task 8: Study on very large scale photovoltaic power generation systems (completed projects/activities) (http://www.iea-pvps.org/index.php?id=35), and the Kosuke Kurokawa Laboratory (KURO LAB), Tokyo University of Agriculture and Technology (TUAT) (http://www.kurochans.net/). In addition, two additional key terms KT10 and KT11 were searched and details indicated in Table 2 and Fig. 2. The most important and relevant studies and contributions about this subject were summarized in this section.

In the work of Kurokawa et al. (1997), a 100 MW very large scale photovoltaic (VLS-PV) system spreading across six deserts (Gobi, Thar, Sonora, Great Sandy, Sahara, Middle East/Abu Dhabi) was studied. It was concluded in the work that Sonora was the costliest for VLS-PV deployment, while the least costly region was Sahara. Kurokawa et al. (2002) also studied a 100 MW VLS-PV in six deserts including Sahara, Negev, Thar, Sonora, Great Sandy, and Gobi. Optimum annual power generation of 194, 159, 163, 172, 176 and 162 GWh/yr were respectively obtained for six locations, whereas generation costs were computed as 5.3, 7.2, 6.6, 6.6, 8.3, and 6.4 cent/kWh respectively, for the selected sites (Kurokawa et al., 2002). In another work of Kurokawa et al. (2002), Life-Cycle Analysis (LCA) was performed for designing a sustainable community with cumulative 1 GW VLS-PV plant (10 plants of 100 MW VLS-PV) in Ito et al. (2004a). A LCA was also adopted to evaluate fixed flat plate system, with sun tracking system (single, horizontal, North–South oriented axis) having flat plate PV module (Kyocera KC120S Poly-Si) for a 100 MW VLS-PV in six deserts (Sahara-Nema, Sahara-Ouarzazate, Negev, Thar, Sonoran, Great Sandy, Gobi) in the work of Ito et al. (2004b). Tracking system in Sahara-Nema was found to be the least costly while the fixed system in Gobi was the most expensive (Ito et al., 2004b). In Ito et al. (2004c), LCA for Kyocera KC 120S Poly Crystalline Silicon (Si), Kaneka LSU Amorphous Si (a-Si) and near future case thin-film Si for a 100 MW VLS-PV in Gobi was conducted; energy payback time, lifecycle CO_2 emission rate and generation cost were also evaluated (Ito et al., 2004c). The work of Sakakibara et al. (2004), investigated Gobi on JERS-1 satellite images by calculating vegetation index of Modified Soil Adjusted Vegetation Index. The study classified surface as rock desert, dune or desert steppe, desert steppe or steppe, shadow, forest, snow or cloud and water. The work of Beneking et al. (2005), presented economic feasibility of VLS-PV in Casablanca and Quarzazate sites in Morocco, Tunis and Gafsa in Tunisia, Porto and Faro in Portugal, and Oviedo and Almeria in Spain; the least costly location was found to be Quarzazate in Morocco. However, it was found in the work that the best conditions for operating VLS-PV would be in Spain (Beneking et al., 2005). Also, Ito et al. (2005a), worked on a 100 MW VLS-PV system with three options of 110 kV TACSR 240, 410 and 680 mm^2, and transmission lines with 330 MW capacity in six locations that are deserts (Sahara, Negev, Thar, Sonoran, Great Sandy, Gobi); it was concluded that the desert site of Gobi had the lowest transmission loss while Sahara desert had the highest transmission loss (Ito et al., 2005a). A LCA was also carried out for m-Si (multicrystalline silicon), a-Si (amorphous silicon), and CdTe (Cadmium Telluride) PV module options for a 100 MW VLS-PV, it was found that m-Si gave the least cost, while a-Si is the costliest of the three materials (Ito et al., 2005b). Requirements for a 100 MW VLS-PV for a desert location (Gobi), was explained by Meisen and Pochert (2006). The work also discussed the estimated annual electricity generation in deserts, including: Great Basin, Chihuahuan, Sonoran, Mojave, Patagonian, Atacama, Great Victoria, Great Sandy, Simpson, Arabia, Gobi, Karakum, Kyzylkum, Takla Makan, Kavir, Syrian, Thar, Lut, Sahara, Kalahari, and Namib (Meisen and Pochert, 2006). Research work on finding a suitable area in six deserts (Gobi, Thar, Sonora, Great Sandy, Sahara, and Negev) for VLS-PV using satellite LANDSAT-7/ETM+ and NOAA/AVHRR images (number of images: 68 on Gobi, 254 on Sahara, 12 on Great Sandy, 15 on Thar, 6 on Sonora, and 6 on Negev), were conducted in the work of Hamano et al. (2007). Potential benefits of electricity generation in the desert (e.g. security of energy supply, peace and poverty alleviation, connected areas etc.) were presented in the study by Free Energy International BV (Free Energy International BV, 2008). The study by Free Energy International BV (2008), presented some aspects of very large scale photovoltaic systems (e.g. socioeconomic, financial, technical and environmental). Other important studies were as carried out in literatures (Mano et al., 2014; Fukae et al., 2003; Komoto et al., 2008; Sato et al., 2009; Ito et al., 2009, 2010b; El-Sudany et al., 2010; Charabi and Gastli, 2011; Stambouli and Koinuma, 2012; Kawase et al., 2013; Komoto et al., 2013; Flazi and Stambouli, 2014).

In all the previous work, there are currently no studies carried out on finding, selecting, defining and identifying the most suitable location selection factors of new VLPVPP investments on global grid and supergrids. This work will be the first in this field, going by the aim of the study. The method adopted in this study, through the integration of 1GOAHIDSM, was reviewed in a detailed manner in this study and in the whole RD^3&D process. Some important studies related to Type 1 and Type 2 Mamdani FIS, Grey theory and mathematics, ISM, MICMAC, and PEST, were presented in several applications (Saracoglu, 2014a,b,c,d,e,f, 2017a,c,b,d,e; Caraveo et al., 2017; Za'in et al., 2017; bin Rodzman et al., 2017; Liu et al., 2013; Li et al., 2007; Guo et al., 2015; Chen, 2012; Luthra et al., 2011; Linss and Fried, 2009; Villacorta et al., 2012; Asan and Asan, 2007; Ho, 2014; Hedayati, 2012). Therefore, this research paper will also contribute to knowledge concerning progress of 1GOAHIDSM-RD^3&D processes, and in the application of Type 2 Mamdani FIS, Grey theory and mathematics, ISM, MICMAC and PEST.

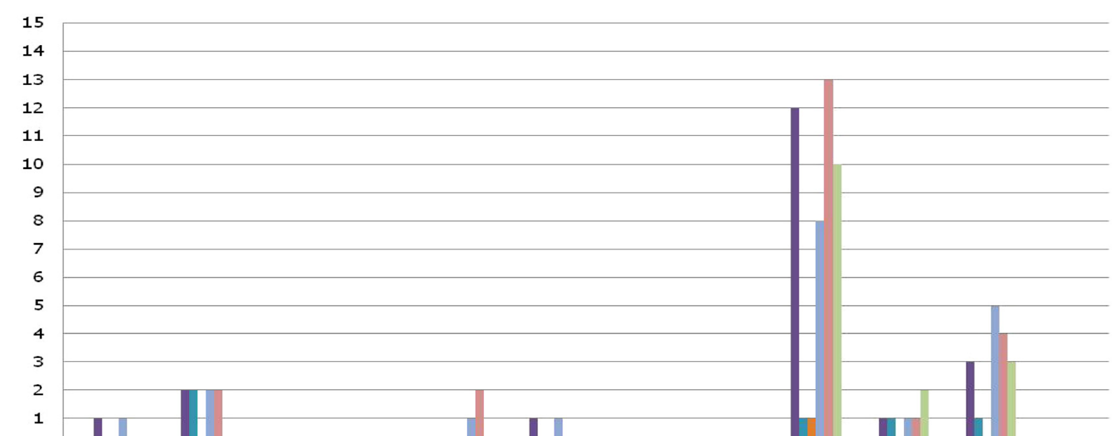
3. Location selection factors for VLPVPPs investments

3.1. Methodology

The location selection factors module of the 1st Generation Original Anatolian Honeybees' Investment Decision Support Methodology (1GOAHIDSM), is globally proposed as an expandable and flexible computer-based collaborative methodology and its respective system under its RD^3&D process, based on the analogy of Original Anatolian Honeybees' characteristics, colonies, and life (Saracoglu, 2016b) (Fig. 3, Electronic Supplementary Material: ESM-1). The 1GOAHIDSM will be described as location selection factors module of 1st generation Original Anatolian Honeybees' Investment Decision Support System (1GOAHIDSS), when it is fully designed during its RD^3&D process. There are three (3) main "*beehives*" in its current methodological form. These "*beehives*" present discriminative and distinguished stages as knowledge gathering and acquisition (1st *Beehive*), knowledge gathering and analysis (2nd *Beehive*), and knowledge analysis and evaluation (3rd

	ACMDL	ASCEOR	ASME	CJO	DOAJ	EI	IJIETAP	JIEM	SD	TFJ	WB	WSP
KT1	0	0	0	0	0	0	0	0	0	0	0	0
KT2	0	0	0	0	0	0	0	0	0	0	0	0
KT3	0	0	0	0	0	0	0	0	0	0	0	0
KT4	1	2	0	3	0	4	0	0	78	17	8	4
KT5	0	7	0	1	0	2	4	8	47	26	10	4
KT6	0	0	0	0	0	0	0	0	15	0	4	0
KT7	7	2	1	8	5	4	0	0	403	17	71	4
KT8	10	7	3	4	4	2	4	0	411	26	118	4
KT9	14	2	4	1	3	1	0	0	551	21	85	5

a)



	ACMDL	ASCEOR	ASME	CJO	DOAJ	EI	IJIETAP	JIEM	SD	TFJ	WB	WSP
KT1	0	0	0	0	0	0	0	0	0	0	0	0
KT2	0	0	0	0	0	0	0	0	0	0	0	0
KT3	0	0	0	0	0	0	0	0	0	0	0	0
KT4	1	2	0	0	0	1	0	0	12	1	3	0
KT5	0	2	0	0	0	0	0	0	1	1	1	0
KT6	0	0	0	0	0	0	0	0	1	0	0	0
KT7	1	2	0	0	1	1	0	0	8	1	5	0
KT8	0	2	0	0	2	0	0	0	13	1	4	0
KT9	0	0	0	0	0	0	0	0	10	2	3	0

b)

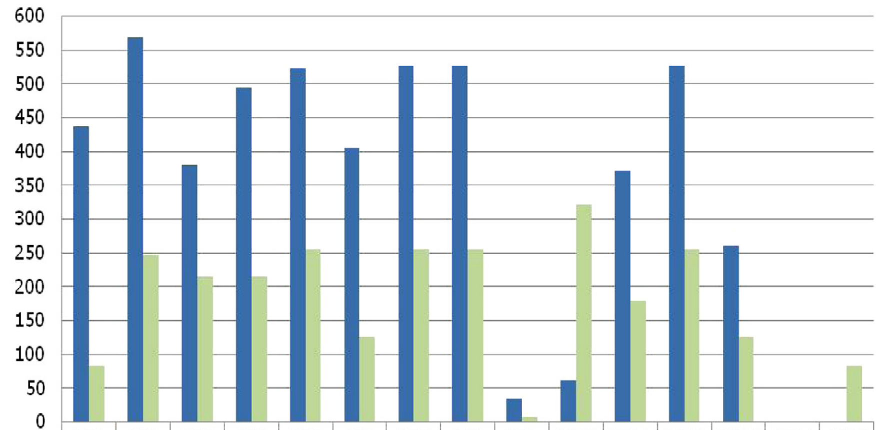
Fig. 1. Search results of keywords (a) scientific online database and journal websites, (b) total number of studies that are somehow related to this study (see Table 2 for abbreviations).

Table 3
Related studies (GoS*: Globalgrid or Supergrid, LS**: Location Selection, AOLSF***: Analyses of Location Selection Factors).

No	Study	GoS*	VLPVPPs	LS**	AOLSF***	Note
1	Adiyabat et al. (2006)	No	No	No	No	"Solar energy potential and photovoltaic (PV) module performance", "Gobi Desert of Mongolia"
2	Ahadi et al. (2014)	No	No	No	No	Reliability of large-scale, grid-connected PV systems
3	Bin and Dichen (2013)	No	No	No	No	Large-Scale Photovoltaic Generation
4	Boran et al. (2010)	No	No	Yes	No	"Multi-criteria axiomatic design", "Grid-connected photovoltaic power plant (GCPP)", "Four evaluation criteria"
5	Brenna et al. (2012)	No	No	No	No	Design layout of the PV plant using a DC bus system
6	Carrión et al. (2008)	No	No	Yes	No	"Environmental decision-support system (EDSS)", "Selecting optimal sites for grid-connected photovoltaic power plants."
7	Cooper and Sovacool (2013)	Yes	No	No	No	"Gobitec concept", "Gobitec project in the Gobi Desert in Northeast Asia"
8	Ehara et al. (2012)	No	No	No	No	"VLS-PV (Very Large Scale Photovoltaic Systems) International Energy Agency Photovoltaic Power Systems Programme (IEA-PVPS) Task 8 group"
9	Faiman (2004)	No	No	No	No	Desert Ecosystem
10	Han et al. (2013)	No	No	No	No	"The large-scale PV power plants (500 MW, 300 MW, 100 MW)"
11	Islam et al. (2014)	No	No	No	No	"Modified Gaussian distribution function Monte Carlo simulation."
12	Ito et al. (2008)	No	No	No	No	100 MW VLS-PV (Very Large Scale Photovoltaic Systems)
13	Ito et al. (2002)	No	No	No	No	100 MW very large-scale photovoltaic power generation (VLS-PV)
14	Ito et al. (2010a)	No	Yes	No	No	"1 GW VLS-PV system in Gobi Desert sc-Si, mc-Si, a-Si/sc-Si, a-Si/μc-Si, CdTe, and CIS PV modules"
15	Ito et al. (2011)	No	No	No	No	20 different PV modules by life cycle analysis (LCA)
16	Komoto (2007)	Yes	Yes	No	No	"Very Large-Scale Photovoltaics (VLS-PC) (Less than 1 GW, however the possibility of 1 GW presented)", "Selected Regions in the Mediterranean, Sahara, Chinese Gobi, Mongolian Gobi, Indian Thar, Australian Desert and the US"
17	Krupa (2013)	No	No	No	No	
18	Kurokawa et al. (1997)	No	No	No	No	100 MW plant size located at 6 desert sites around the world
19	Obara et al. (2014)	No	No	No	No	"Large-scale photovoltaics", "temperature distribution", "electrical conversion efficiency of a photovoltaic module", "wind conditions "
20	Paatero and Lund (2007)	No	No	No	No	Large-scale photovoltaic power integration
21	Phillips (2013)	No	No	No	No	Sustainability for large-scale photovoltaic (PV) solar power plants
22	Sánchez-Lozano et al. (2014)	No	No	Yes	No	"Geographic Information System (GIS)", "Evaluation and classification of best sites to implant photovoltaic solar farms"
23	Sánchez-Lozano et al. (2013)	No	No	Yes	No	"Geographic Information System (GIS)", "Multi-criteria decision making (MCDM) methods", "Evaluate potential sites to locate a solar plant"
24	Solomon et al. (2010b)	No	No	No	No	PV-grid matching simulations
25	Solomon et al. (2010c)	No	No	No	No	"Power capacity of storage", "PV system size"
26	Solomon et al. (2010a)	No	No	No	No	"Very large-scale photovoltaic power (VLS-PV), Effect on grid ramping requirements"
27	Uchiyama et al. (2013)	No	No	No	No	"Geographic information system (GIS) Evaluate amounts of installation capacity of large-scale PV systems,"
28	Yang et al. (2011)	No	No	No	No	"100 MW VLS-PV (Very Large Scale Photovoltaic Systems), International Energy Agency Photovoltaic Power Systems Programme (IEA-PVPS) Task 8 group"
29	Yokota and Kumano (2013)	No	N/A	N/A	N/A	Optimal candidate sites for the mega-solar allocation
30	Yuventi (2013)	No	No	No	No	"Identify layouts, maximize power performance and best utilize land area"
31	Yuventi et al. (2013)	No	No	No	No	Organizational structures and behaviours

Beehive). Each "*beehive*" has its own "*honeycombs*", "*beeswaxes*" and "*honeycomb cells*". A "*honeycomb cell*" represents a unique method, data set, information set, tool, and any other special activity (e.g. generate keywords, search words, watchwords). A "*honeycomb*" represents a group of cells for a unique group of methods, data sets, information sets, tools, and any other special activities. It is aimed that many 1GOAHIDSM's "*honeycombs*" will be automated with artificial intelligence applications in future. Some previously applied methods on "*honeycomb cells*" of 1GOAHIDSM are interrelated with Type-1 fuzzy logic theory, Decision Making Trial and Evaluation Laboratory (DEMATEL), grey theory, and Weighted Product Method (WPM) (Saracoglu, 2016b). When an activity is performed on any "*honeycomb cell*" during 1GOAHIDSM's application, that "*honeycomb cell*" is fed with honey as a visual presentation. Identities of developers and users are under protection by the representation of users as "*queen bees*" and "*worker bees*".

Open Source Initiative (OSI) is the systems development philosophy of 1GOAHIDSM (1GOAHIDSS). Any system developer is able to develop or improve any part of it and add any "*honeycomb cell*" at anytime. For instance, visualization of data honeycomb cells may be developed and integrated like Gephi plugins or clustering of factors and criteria honeycomb cells by DEMATEL or Interpretive Structural Modelling (ISM); Impact Matrix Cross-Reference Multiplication Applied to a Classification (MICMAC), may also be applied, coded and integrated by DEMATEL or ISM MICMAC users. The 1GOAHIDSM can be further researched, developed and operated during its system development and operation lifetime, to the new generation titles (e.g. 2nd generation: 2GOAHIDSM (2GOAHIDSS), 3rd generation: 3GOAHIDSM (3GOAHIDSS)) with



	SE1	SE2	SE3	SE4	SE5	SE6	SE7	SE8	SE9	SE10	SE11	SE12	SE13	SE14	SE15
KT10	438	569	380	494	524	405	526	526	34	62	371	527	261	0	0
KT11	83	246	215	215	256	126	256	256	8	321	180	256	126	0	84

Fig. 2. Total number of studies found on search engines (see Table 2 for abbreviations).

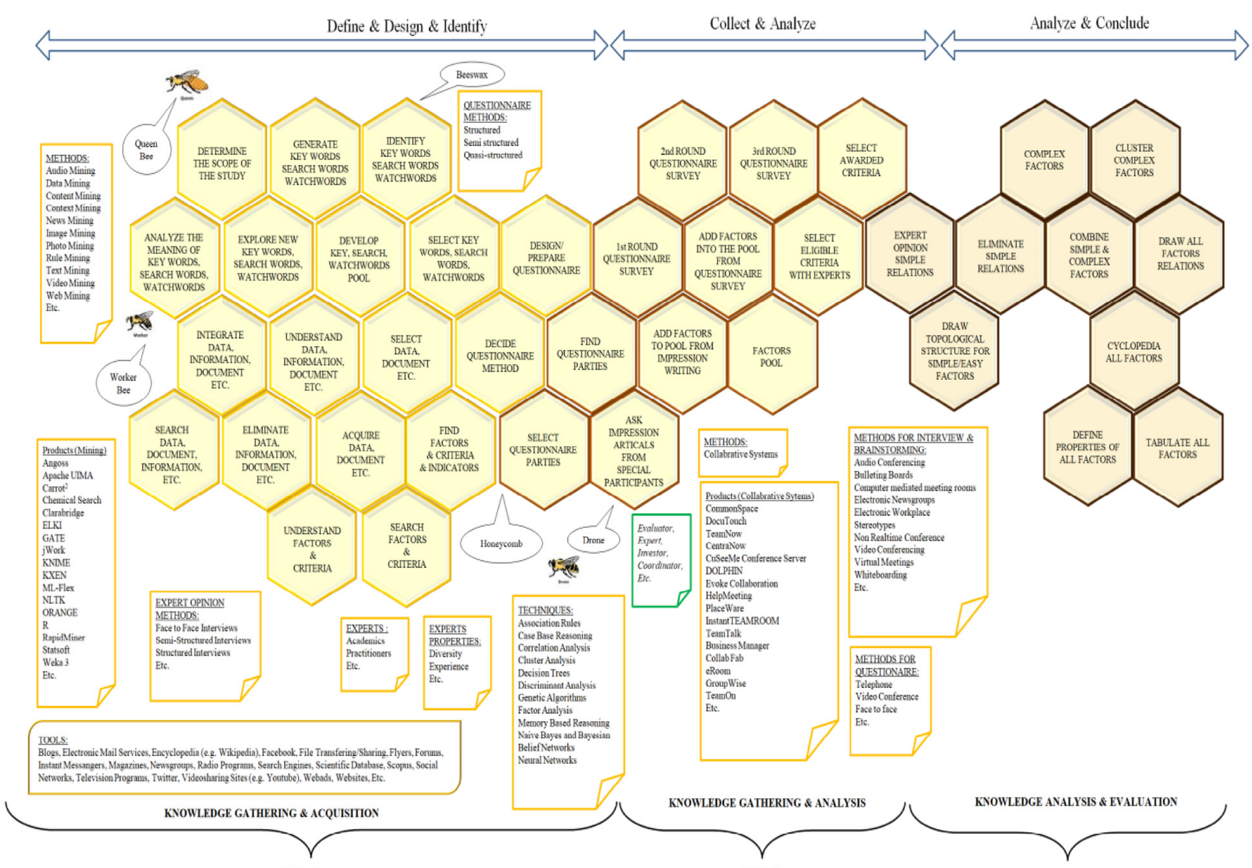


Fig. 3. 1GOAHIDSM honeycomb cells in this study (see ESM-1).

the breakthrough in systems improvements. Its development and usage are free, and its user interfaces developed in the same manner as the System Advisor Model (SAM) (https://sam.nrel.gov/).

1GOAHIDSM and its successors (e.g. 2GOAHIDSM) are planned to have many other investment related modules, like location selection factors. Some of these modules are location data and information module, location selection module, power plant technology data and information module, power plant design data and information module, power plant design module, power plant investment data and information module, and power plant investment module. All will have their own unique aims. For example, location selection module will include several Multicriteria Decision Making (MCDM) methods (e.g. Analytic Hierarchy Process (AHP), Elimination and Choice Translating Reality (ELECTRE), Decision EXpert for Education (DEXi), Preference Ranking Organisation Method For Enrichment Evaluations (PROMETHEE), QUALItative FLEXible (QUALIFLEX), Organization, Rangement Et Synthese

Table 4
Some official websites of some agencies and authorities.

No	Agency & authority titles	Website address
1	European Photovoltaic Industry Association	http://www.epia.org/
2	European Photovoltaic Technology Platform	http://www.eupvplatform.org/
3	International Energy Agency, Photovoltaic Power Systems Programme	http://www.iea-pvps.org/
4	Asian Photovoltaic Industry Association	http://www.apvia.org/
5	Sophia European Research Infrastructure	http://www.sophia-ri.eu/
6	SunSpec Alliance	http://www.sunspec.org/
7	Malaysian Photovoltaic Industry Association	http://www.mpia.org.my/
8	South African Photovoltaic Industry Association	http://www.sapvia.co.za/
9	Romanian Photovoltaic Industry Association	http://rpia.ro/
10	Korea Photovoltaic Industry Association	http://kopia.asia/
11	Italian Photovoltaic Industry Association	http://www.gifi-fv.it/
12	Taiwan Photovoltaic Industry Association	http://www.tpvia.org.tw/
13	Solar Electric Power Association	http://www.solarelectricpower.org/

De Donnes Relationnelles (ORESTE) and the Multi-Objective Optimization Methods (MOOM) such as: Multi-Objective Optimization on the basis of Ratio Analysis (MOORA), Adaptive Range Multi-Objective Genetic Algorithm (ARMOGA). This paper also aimed at drawing the interest of researchers to 1GOAHIDSM RD^3&D process.

3.2. Analysis

Application of this study was performed based on authors' experiences, and findings on RE power plants and based on 1GOAHIDSM between 2014 and 2015 (Fig. 3). Total effort for this study was expected to be scaled down by this approach. Case-specific key and watchwords or phrases were very carefully found, selected, added and searched. These keywords include *location, site, land, place, area, selection, location selection, site selection, land selection, place selection, area selection, supergrid, global grid* and *DESERTEC*, alongside some additional case-specific keywords (e.g. *photovoltaics*, *PV*). Almost 2000 scientific documents were reviewed in a detailed manner in this study, for only these additional case specific keywords. Scientific documents including official websites of some agencies and authorities were regularly visited, and effectively used during this study (Table 4).

Furthermore, structured questionnaire survey via e-mail was conducted for managers, engineers, executives, and experts in the field in 2014. Design of the survey was based on the principles of Delphi method (Dalkey and Helmer, 1963; Turoff and Linstone, 2002). Three round survey (limitation at once with three evaluations) were sent in Microsoft Office Excel and Apache OpenOffice Calc files (see Ishikawa et al., 1993; Chen and Weng, 2009; Fanning, 2005; Trochim, 2006). Sample questionnaire files were sent via e-mail to 248 respondents. About 83% deliverable rate was recorded. About 2% of participants preferred to use questionnaire files whereas 2% of participants also preferred to write articles like impression articles as e-mail text messages, or as e-mail attachments (see Kervyn et al., 2009 for impression writing) (Fig. 4, Table 5). In this research work, a total of seven (7) experts participated in the preliminary screening investment stage, while six (6) experts participated in the pre-feasibility investment stage. In this study, missing, imprecise, insoluble and unrealistic data, values and information were treated (Halo Effect, Horns Effect, etc.) (see Anand et al., 1996; Han, 1994; Wang and Wang, 2004; Zha et al., 2013; Tsikriktsis, 2005). About 8 participants were experts (E) from 8 different countries (Europe: 5, Asia: 3); 46% of contribution was for pre-feasibility stage. Data and information review and analysis rate was 44%. Impression articles (much more difficult) were analysed based on Procedure 1 (WordNet, 2010) (factors preference and selectivity). Finally, mappings were developed (ESM-2 to ESM-5).

Table 5
Experts contribution details.

No	Information type	Investment stages	Country
1	Impression article	Both	Israel
2	Impression article	Both	South Korea
3	Impression article	Both	Germany
4	Impression article	Both	Netherlands
5	Questionnaire	Both	Italy
6	Questionnaire	Pre-feasibility	France
7	Questionnaire	Preliminary screening	India
8	Questionnaire	Preliminary screening	Denmark

Awarded factor selection was an important and complicated task. Semi-detailed, partially precise, defined, predictable and not fully perceived definitions, conditions and information, had to be evaluated during this task. In most cases, some factors were even undefined and unperceived by decision maker. Grey Theory (Deng, 2002; Liu and Forrest, 2007), and Fuzzy Logic Theory (Bellman et al., 1966; Goguen, 1967; Zadeh et al., 1975) could be used for modelling in these conditions. A Type-2 fuzzy logic model was tried in this ill-posed problem (linguistic uncertainties, unsharpness) in both investment stages [see Sepulveda et al., 2007; Zhai and Mendel, 2011; Chen and Wang, 2013; Martino and Sessa, 2014]. Motivation of Type-2 fuzzy logic model approach was shortly related to certain issues. First, experts' knowledge and expertise on PV power plants were imperfect, uncertain and not sharp in terms of experts themselves, and this methodology or system (i.e. 1GOAHIDSM) in many cases, because of experts' direct or indirect experience level in PV power plants project development phases (perfect information: always impossible case vs. imperfect information: always possible case). Second, experts' knowledge on location selection of PV power plants and their methods were imperfect and uncertain in terms of the adopted methodology or system (1GOAHIDSM), because of experts' experience level in PV power plants project development phases, and also MCDM applications (perfect information: always impossible case vs. imperfect information: always possible case). Third, experts' perception on languages and terminologies were imperfect, undefined and unpredictable in terms of experts themselves and this methodology or system (1GOAHIDSM), because of experts' language abilities and capabilities (perfect information: always impossible case vs. imperfect information: always possible case). Fourth, determination of object characteristics degrees was very low and footprint of uncertainty was very high in Type-2 fuzzy logic model approach vs. Type-1 fuzzy logic model approach (Abdulshaheed, 0000). Fifth, development of a methodology or system (1GOAHIDSM) in the philosophy of "uses data to do more with less" (see Konkel, 0000). Mamdani-type fuzzy logic system (FLS, FIS: fuzzy inference systems) was adopted for awarded factors selection process (see Mamdani, 1974). Inspiration and intuition of adopting a Mamdani type FLS came from Wierman's wording "Future Looks Fuzzy", "Natural language", "Managing uncertainty", "Decision making" and "momentous paradigm change" (Wierman, 2010). There were also some other studies in different research and application fields with type 2 fuzzy logic. For instance, Lee and others presented an application of Type-2 fuzzy logic for personal diabetic-diet recommendation (Lee et al., 2010b), and also Type-2 fuzzy logic for diet assessment (Lee et al., 2010a). Rani

Procedure 1: Semantics (meanings of words/phrases) evaluation of experts for factors on impression articles

Initialize: Impression Article$_{i_{\mathrm{Expert}_j}}$
Inputs: Factor$_k$
ForEach i: $1 \le i \le n \wedge i \in \mathrm{N}$
ForEach j: $1 \le j \le m \wedge j \in \mathrm{N}$
ForEach k: $1 \le k \le o \wedge k \in \mathrm{N}$
If Impression Article$_{i_{\mathrm{Expert}_j}}$ includes <paragraph> <sentence> "Factor$_k$" → "Factor$_k$ is Desirable"
If Impression Article$_{i_{\mathrm{Expert}_j}}$ includes <paragraph> <sentence> "Factor$_k$" ∧ "not" → "Factor$_k$ is Undesirable"
If Impression Article$_{i_{\mathrm{Expert}_j}}$ includes <paragraph> <sentence> "Factor$_k$" ∧ "words, verbs, etc. in negative meanings in the context" → "Factor$_k$ is Undesirable"
If Impression Article$_{i_{\mathrm{Expert}_j}}$ includes <paragraph> <sentence> NULL "Factor$_k$" → "Factor$_k$ is Neutral"
EndIf
EndIf
EndIf
EndIf
EndFor
EndFor
EndFor
Outputs: Mappings of estimation of evaluations of Expert$_j$ on Factor$_k$ by Impression Article$_i$

Visit: WordNet®, (http://wordnet.princeton.edu/wordnet/) for terms and approach (WordNet, 2010).

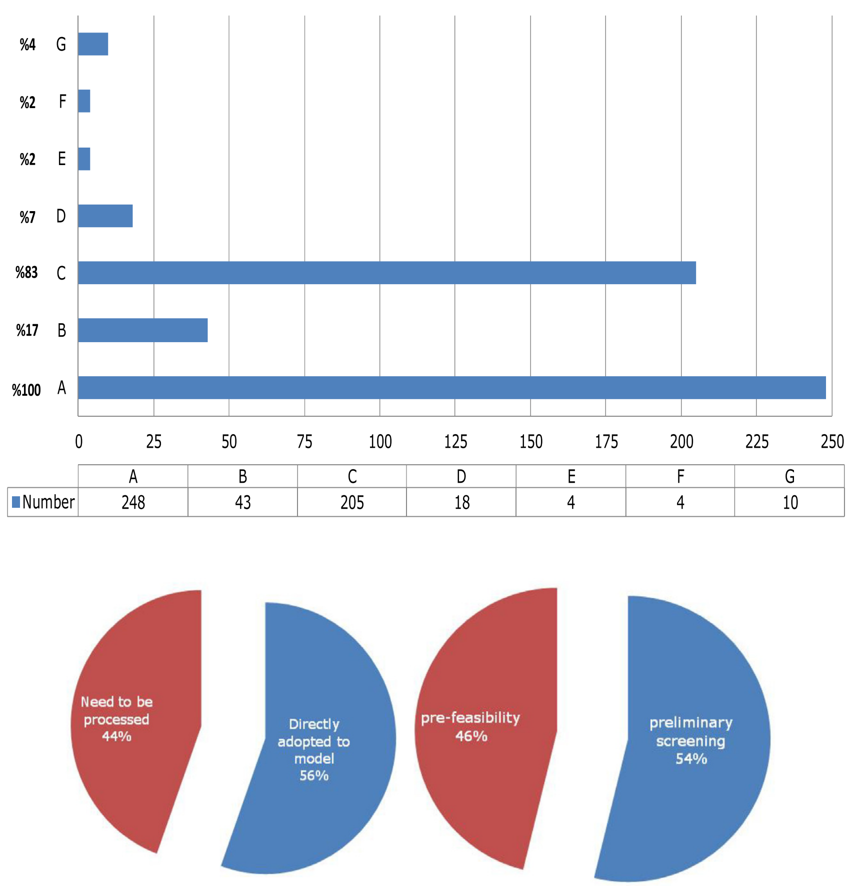


Fig. 4. Survey summary (a) with bar charts (A: E-mails sent, B: Undeliverable e-mails, C: Deliverable e-mails, D: Received replies, E: Reply of questionnaire, F: In the form of impression articles, G: Reply of polite improperness/unavailability), and (b) survey descriptive statistics with pie charts.

and others presented usage of fuzzy co-clustering algorithm for semantic question answering retrieval system (Rani et al., 2014), and others (Caraveo et al., 2017; Amador-Angulo and Castillo, 2018; Ontiveros-Robles et al., 2017; Castillo et al., 2016). Toolboxes and software packages were helpful and easy for modelling and mathematical calculations. JuzzyOnline was used in this study (http://juzzyonline.wagnerweb.net) (Wagner, 2013; Wagner et al., 2014) (possible others e.g. DIT2FLS by Toolbox Cognitive & Uncertainty Research Group: http://dit2fls.com/; Type-2 Fuzzy Logic Software for Matlab by Karnik, Liang, Liu, Wu, Joo and Mendel: http://sipi.usc.edu/~mendel/software/). Some studies were helpful for modelling Type-2 fuzzy logic (Aghajani et al., 2011; Liang and Mendel, 2000; Hung and Yang, 2004; Herrera et al., 2009). Models, applications and results were applied online in this study. The current model (fuzzy general Type-2, 4 slices, Mamdani, product connective and inference t-Norm, centroid type-reduction defuzzification) was built on some assumptions (ESM-6). In addition, first-hand experience in engineering studies was very important on accuracy, precision and correctness of judgements and decisions. Above all, know-how on a specific subject was also very crucial. Tools for content, context, and text mining were very helpful in these kinds of analysis. Carrot2 tool (http://project.carrot2.org/) was used for gathering interrelations between criteria's terms and terms on documents (Carrot2, 2013; Zamir and Etzioni, 1999; Osinski and Weiss, 2005).

Clustering of factors is very crucial in these kinds of studies. Cluster analysis is a general logic process, formulated as a procedure by which objects were grouped together into groups based on their similarities and differences (Palumbo et al., 2010; Trebuňa and Halčinová, 2013). There are two separate consecutive clustering analyses in this study. These are simple and complex factor clustering analyses. Simple factor clustering is for factors that are simple enough to be clustered by perception while complex factors clustering is for almost impossible factors that are to be evaluated by experts' cognition on linguistic terms. They needed to be computed by mathematical methods or systematic approaches. In both clustering cells, magical number 7 was taken as a constraint. A procedure (see Procedure 2) was used to force all factors to obey a structure according to magical number 7 rule (7 ± 2 rule) (see Miller, 1956; Shiffrin and Nosofsky, 1994) (ESM 7).

The main aim of obeying this rule is the intention of future location selection studies by MCDM or MOOMs. However, all factors or some preferred ones could be reorganized based on several methods. These kinds of constraints made the problem much difficult. Aggregation nodes were added to obey this constraint whenever clustering was impossible in natural conditions. These aggregation nodes were defined based on literature and knowledge. Evaluations by Procedure 2 had to be performed several times until transient period (change between consecutive evaluations) on perception, reached steady state condition (no change between consecutive evaluations). Steady state conditions could not be predictable in these studies, hence evaluations had to be performed as much as possible; duration of these evaluations might take several months or even years. After two or three attempts, factors that could not be matched on each evaluation could be put into complex factors cells. Other factors can be accepted as simple factors by its structured clusters. In this study, there are two evaluations across time (EDM-T1 and EDM-T2 where EDM: Expert Decision Maker) (ESM 7).

In complex factors clustering, any clustering analysis (cross-impact method, DCMPOS: decomposition of non-directed graphs, etc.) could be executed. In this study, a grey Interpretive Structural Modelling (ISM) approach (see Lendaris, 1980) on PEST (Political, Economic, Social and Technological) (SLEPT, PESTEL, PESTLE, STEEPLE, STEEPLED, DESTEP and STEER extensions) framework was deployed (Table 6). PEST and its extensions were analysed (Political, Economic, Social, Technological, Legal, Environmental, Ethics, Demographic, Ecological, Socio-cultural, Regulatory). Some of these main factors were assigned as main factors according to their relative relations. Remaining ones were eliminated from this list.

Even though ISM method is based on working by several people with heterogeneous groups, there is only one person with just one evaluation in this study. Main reason for this situation is the lack of resources and prematurity of this research; however, findings in this work could be used for worldwide applications. Principles of ISM method (i.e. the original method) is expressed as:

Step 1: establishing contextual relationship by four symbols
V: *i* influences/impacts on *j*,
A: *j* influences/impacts on *i*,
X: *i* and *j* influence/impacts on each other,
O: *i* and *j* are unrelated,
Step 2: developing a structural self-interaction matrix (SSIM with four symbols)
Step 3: developing a reachability matrix (RM) with its transitivity property
$\mathrm{SSIM}_{(i,j)}$:V→$\mathrm{RM}_{(i,j)}$:1 and $\mathrm{RM}_{(j,i)}$:0,
$\mathrm{SSIM}_{(i,j)}$:A→$\mathrm{RM}_{(i,j)}$:0 and $\mathrm{RM}_{(j,i)}$:1,
$\mathrm{SSIM}_{(i,j)}$:X→$\mathrm{RM}_{(i,j)}$:1 and $\mathrm{RM}_{(j,i)}$:1,
$\mathrm{SSIM}_{(i,j)}$:O→$\mathrm{RM}_{(i,j)}$:0 and $\mathrm{RM}_{(j,i)}$:0),
Step 4: partition of the reachability matrix into different levels
Step 5: conversion of the reachability matrix into conical form
Step 6: draw the graph [see Attri et al., 2013; Cagno et al., 2014; Kumar et al., 2014; Verma, 2014 for all details].

In this study, driving power and dependence power of factors were analysed using Impact Matrix Cross-Reference Multiplication Applied to a Classification (MICMAC®) tool for supporting ISM method in complex factors clustering analysis. MICMAC® method was first presented in a report by Duperrin and Godet (Kumar et al., 2014; Duperrin and Godet, 1973). MICMAC® method tried to organize independent and dependent variables. It helped to build a topology for factors in direct and indirect classifications (Godet and Degenhardt, 1994). Principles of MICMAC® tool (original and basic method) are based on clustering of factors into four groups. The first cluster consisted of elements that had weak driving power and weak dependence power. These factors were not related with the system and they are expressed as autonomous factors. The second cluster consists of elements that have weak driving power but strong dependence power while the third cluster consists of elements with strong driving power and also strong dependence power. These factors affect each other and also give feedback to each other (influence chains and reaction loops); they are expressed as linkage factors. The fourth cluster consists of elements that have strong driving power but weak dependence power; the elements are expressed as independent factors (Godet and Degenhardt, 1994; Kannan et al., 2009) (Table 7).

Grey theory principles empowered modelling of vagueness and subjectiveness of human feeling, judgement, perspective, recognition, complexity, and confusing nature of information as shown in Table 8 (Zavadskas et al., 2009).

Principles of Grey Theory (Zavadskas et al., 2009; Chen and Tzeng, 2004; Liu et al., 2012; Turskis and Zavadskas, 2010; Zhou and Xu, 2006).
α is the lower limit of $\otimes x$, γ is the upper limit of $\otimes x$.
Three kinds of numbers including black, white and grey are defined as such:
$\alpha \to -\infty$ and $\gamma \to \infty$ then $\otimes x$ is the black number; $\alpha = \gamma$ then $\otimes x$ is the white number.
Otherwise $\otimes x = [\alpha, \gamma]$ then $\otimes x$ was the grey number.
Grey numbers' operations are:

$$\text{Addition}: \otimes n_1 + \otimes n_2 = (n_{1\alpha} + n_{2\alpha}, n_{1\gamma} + n_{2\gamma}) \quad (1)$$

Procedure 2. Simple factors clustering

```
Inputs: Factor_i
  ForEach i: 1 ≤ i ≤ n ∧ i ∈ N
    Select metacentric factors amongst all factors
      ForEach j: 1 ≤ j ≤ m ∧ j ∈ N
        List surrounding simple factors for its MF_j where MF_j: metacentric factor_j
          Evaluate distances (7 point Likert type scale) of surrounding simple factors from its MF_j
            If MF_j obeys magical number 7 rule (7±2 rule) then keep it as it is.
              If MF_j does not obey magical number 7 rule then add or find aggregation nodes
              EndIf
            EndIf
      EndFor
  EndFor
Outputs: Simple factors clusters
```

Table 6
PEST and its extensions (main clusters of this study).

PEST	SLEPT	PESTEL	PESTLE	STEEPLE	STEEPLED	DESTEP	STEER
Political	Political	Political	Political	Political	Political	Political	
Economic	Economic	Economic	Economic	Economic	Economic	Economic	Economic
Social	Social	Social	Social	Social	Social	Social	
Technological	Technological	Technological	Technological	Technological	Technological	Technological	Technological
	Legal	Legal	Legal	Legal	Legal		
		Environmental	Environmental	Environmental	Environmental		
				Ethics	Ethics		
					Demographic	Demographic	
						Ecological	Ecological
							Socio-cultural
							Regulatory

Note: Political, Economic, Technological, Environmental were selected in preliminary screening stage in findings of this study (light yellow background colour).

$$\text{Additive inverse}: -\otimes n_1 = (-n_{1\alpha}, -n_{1\gamma}) \tag{2}$$

$$\text{Subtraction}: \otimes n_1 - \otimes n_2 = (n_{1\alpha} - n_{2\alpha}, n_{1\gamma} - n_{2\gamma}) \tag{3}$$

$$\begin{aligned}\text{Multiplication}: \otimes n_1 \times \otimes n_2 = (&min(n_{1\alpha} \times n_{2\alpha}, n_{1\gamma} \times n_{2\gamma},\\ &n_{1\alpha} \times n_{2\gamma}, n_{1\gamma} \times n_{2\alpha}), max(n_{1\alpha} \times n_{2\alpha}, n_{1\gamma} \times n_{2\gamma},\\ &n_{1\alpha} \times n_{2\gamma}, n_{1\gamma} \times n_{2\alpha}))\end{aligned} \tag{4}$$

$$\begin{aligned}\text{Division}: \otimes n_1 \div \otimes n_2 = (&min(n_{1\alpha} \div n_{2\alpha}, n_{1\gamma} \div n_{2\gamma}, n_{1\alpha} \div n_{2\gamma},\\ &n_{1\gamma} \div n_{2\alpha}), max(n_{1\alpha} \div n_{2\alpha}, n_{1\gamma} \div n_{2\gamma}, n_{1\alpha} \div n_{2\gamma}, n_{1\gamma} \div n_{2\alpha}))\end{aligned} \tag{5}$$

$$\text{Multiplication by real numbers: } \mathrm{k} \times (\otimes n_1) = (\mathrm{k}n_{1\alpha}, \mathrm{k}n_{1\gamma}) \tag{6}$$

$$\text{Power of grey numbers}: (\otimes n_1)^{\mathrm{k}} = (n_\alpha^{\mathrm{k}}, n_\gamma^{\mathrm{k}}) \tag{7}$$

$$\begin{aligned}&\text{Whitenization of grey numbers}: \otimes x = [\alpha, \gamma]\\ &\text{then } \tilde{\otimes} x = \mathrm{Q} \times \alpha + (1 - \mathrm{Q}) \times \gamma, \mathrm{Q} \in [0, 1]\end{aligned} \tag{8}$$

if $\mathrm{Q} = \frac{1}{2}$, then the whitenization is referred to as equal weight mean whitenization.

Linguistic terms and their representative grey numbers or scales in this study are defined as in ESM-8. Linguistic relations are directly defined by English statements (English as foreign language) and EDM (mother language: e.g. Turkish, non-bilingual or multilingual) directly worked with these statements for independency and dependency of factors. Complex factor clustering was analysed by using Procedure 3 (ESM-9).

Evaluations by Procedure 3 had to be performed several times. In this study, there was only one evaluation across time as presented in EDM-T1 (Fig. 5). Finally, clustered structure was gathered as in ESM-9.

3.3. Results

Location selection factors for investments into VLPVPPs were investigated in different project investment development stages (Table 9). The identified, defined, selected and awarded factors were respectively presented in preliminary screening and prefeasibility investment stages in ESM-6, ESM-10, and Table 10. An overall defuzzified threshold value (ODT) was defined and selected in this study. The overall defuzzified value was a crisp value or number gathered after defuzzification process of Type-2 fuzzy logic model application and calculation. The threshold was defined as "*level at which something starts to happen*", "*level, rate, or amount at which something comes into effect*", "*...an amount, level, or limit on a scale. When the threshold is reached, something else happens or changes*". (https, 0000a,b,c). The ODT was the selected overall defuzzified value, that factors were awarded above it and rejected below it; the value was selected as 0.500 in this study. As a result, eleven (11) unclustered criteria in preliminary screening, and 191

Table 7
MICMAC analysis (dependence power, driving power and clusters).

Dependence \ Driving	Weak	Strong
Weak	I	IV
Strong	II	III

Table 8
Meaning of information (Zavadskas et al., 2009).

	White	Grey	Black
Information	Known	Incomplete	Unknown
Appearance	Bright	Grey	Dark
Process	Old	Replace old with new	New
Property	Order	Complexity	Chaos
Methodology	Positive	Transition	Negative
Attitude	Seriousness	Tolerance	Indulgence
Conclusion	Unique solution	Multiple solution	No results

Procedure 3. Complex factors clustering by Grey ISM MICMAC on PEST and its extensions clusters (in short form)

Inputs 1: Complex factors$_i$
Inputs 2: PEST extensions main factors$_j$
Inputs 3: Linguistic terms and their representative grey scales$_k$
List Complex factor$_i$ i: $1 \le i \le n \wedge i \in \mathrm{N}$
List PEST extensions main factors$_j$ j: $1 \le j \le m \wedge j \in \mathrm{N}$
Merge Complex factor$_i$ i: $1 \le i \le n \wedge i \in \mathrm{N}$ ∧ PEST extensions main factors$_j$ j: $1 \le j \le m \wedge j \in \mathrm{N}$
ForEach Complex factor$_i$ i: $1 \le i \le n \wedge i \in \mathrm{N}$ ∧ PEST extensions main factors$_j$ j: $1 \le j \le m \wedge j \in \mathrm{N}$
Select Linguistic terms$_k$ k: $1 \le k \le l \wedge k \in \mathrm{N}$
EndFor
Create Structural Self-Interaction Matrix (SSIM) by linguistic terms$_k$ k: $1 \le k \le l \wedge k \in \mathrm{N}$
Assign Representative grey scales of linguistic terms$_k$ k: $1 \le k \le l \wedge k \in \mathrm{N}$ on SSIM
Create Reachibility Matrix by grey scales of linguistic terms$_k$ k: $1 \le k \le l \wedge k \in \mathrm{N}$
Calculate Dependence Power$_i$ i: $1 \le i \le n \wedge i \in \mathrm{N}$ ∧ Dependence Power$_j$ j: $1 \le j \le m \wedge j \in \mathrm{N}$
Calculate Driving Power$_i$ i: $1 \le i \le n \wedge i \in \mathrm{N}$ ∧ Driving Power$_j$ j: $1 \le j \le m \wedge j \in \mathrm{N}$
Do Level partition (iterations)
EndDo
Plot ISM Model
List Complex factor$_i$ i: $1 \le i \le n \wedge i \in \mathrm{N}$ ∧ PEST extensions main factors$_j$ j: $1 \le j \le m \wedge j \in \mathrm{N}$ ∧ Dependence Power$_i$ i: $1 \le i \le n \wedge i \in \mathrm{N}$ ∧ Dependence Power$_j$ j: $1 \le j \le m \wedge j \in \mathrm{N}$ ∧ Driving Power$_i$ i: $1 \le i \le n \wedge i \in \mathrm{N}$ ∧ Driving Power$_j$ j: $1 \le j \le m \wedge j \in \mathrm{N}$
Plot MICMAC Model
Output: Complex factors clusters on PEST and its extensions clusters

unclustered criteria in the pre-feasibility, were preferred in this study (Table 9). There was only one highest overall defuzzified value (ODV) of 0.660 for Global Horizontal Irradiation (GHI) in preliminary screening stage (ESM-6, ESM-10). The highest ODV in pre-feasibility stage was 0.658 (ESM-10). There were 27 unclustered criteria with this highest ODV. If ODT was selected as approximately 0.55, then there would be only 6 unclustered criteria in the preliminary screening stage. These factors would respectively be GHI, water availability conditions, governments supergrid integration policy, political, war, terror and security conditions, supergrid business climate and conditions, and High Voltage Direct Current and High Voltage Alternating Current (HVDC and HVAC) electrification grid infrastructure. Similarly, there would be only 31 unclustered criteria in pre-feasibility stage. Research studies for location selection purpose would be easier by higher preferred ODT because there were 11 unclustered criteria in the preliminary screening stage, and 191 unclustered criteria in pre-feasibility stage for ODT of 0.500. Moreover, there were 6 and 31 unclustered criteria for ODT of 0.55. If the highest ODT was preferred, then there would be only 1 criterion (i.e. Global Horizontal Irradiation) in preliminary screening stage and 27 unclustered criteria in pre-feasibility stage (ESM-10).

Main structures of PV power plant (solar field PV panels and their foundations, inverters and transformers), approximate peak installed power (P_{peak}) ($\mathrm{kW_p}$) and approximate net annual electricity generation (E_{solar}) (kWh) were also considered in this study. In this work, approximate net annual electricity generation was accepted as expressed in Eq. (9).

$$E_{solar} = A_a \times GHI_a \times \eta_{mo} \times \eta_{te} \times \eta_{so} \times \eta_{sh} \times \eta_{sn} \times \eta_m \times \eta_w \times \eta_c \times \eta_{lid} \times \eta_{nap} \times \eta_{age} \times \eta_{inv} \times \eta_{paf} \tag{9}$$

where E_{solar}: net annual solar electricity generation (kWh); A_{a}: array area of solar field (m^2); $\mathrm{GHI_a}$: annual global horizontal irradiation ($\mathrm{kWh/m^2/y}$); η_{mo}: module efficiency (%); η_{te}: module temperature efficiency (%); η_{so}: soiling efficiency (%); η_{sh}: shading efficiency (%); η_{sn}: snow efficiency (%); η_{m}: mismatch efficiency (%); η_{w}: wiring efficiency (%); η_{c}: connections efficiency (%); η_{lid}: light induced degradation efficiency (%); η_{nap}: nameplate efficiency (%); η_{age}: age efficiency (%); η_{inv}: inverter efficiency (%); η_{paf}: plant availability factor (%) (for further information look at losses and

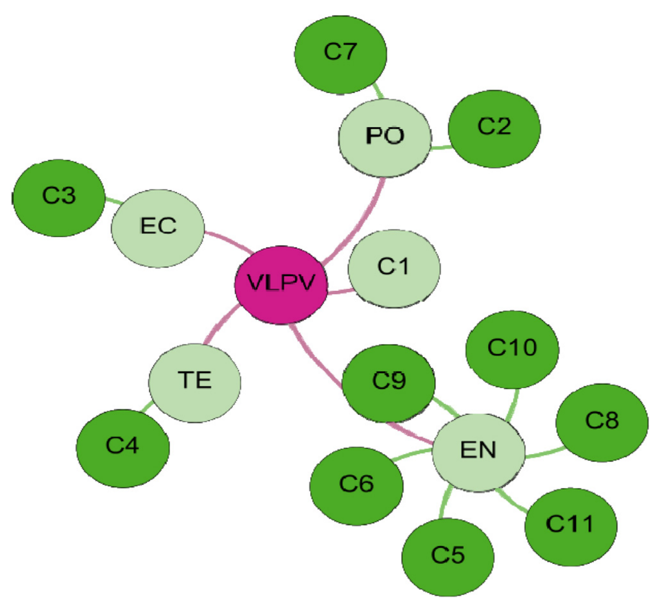


Fig. 6. Grey ISM MICMAC on PEST and its extensions clusters in preliminary screening stage EDM-T1 visualization by Fruchterman Reingold layout in Gephi (http://gephi.github.io/) (see Fruchterman and Reingold, 1991; Bastian et al., 2009) (PO: Political, EC: Economic, TE: Technological, EN: Environmental; C1: Global Horizontal Irradiation (GHI), C2: Governments supergrid integration policy, C3: Supergrid business climate and conditions, C4: HVDC & HVAC electrification grid infrastructure, C5: Land use, allocation and availability, C6: Geological conditions, C7: Political, war, terror & security conditions, C8: Topographical conditions, C9: Climatic conditions, C10: Water availability conditions, C11: Natural disaster/hazard conditions.

Structural Self-Interaction Matrix-EDM-T1

		C1 Global Horizontal Irradiation (GHI)	C2 Governments supergrid integration policy	C3 Supergrid business climate and conditions	C4 HVDC & HVAC electrification grid infrastructure	C5 Land use, allocation and availability	C6 Geological conditions	C7 Political, war, terror & security conditions	C8 Topographical conditions	C9 Climatic conditions	C10 Water availability conditions	C11 Natural disaster/hazard conditions	C12 Political	C13 Economic	C14 Social	C15 Technological	C16 Legal	C17 Environmental	C18 Ethics	C19 Demographic	C20 Ecological	C21 Socio-cultural	C22 Regulatory
C1	Global Horizontal Irradiation (GHI)	X	O	O	O	O	O	O	O	O	O	O	O	O	O	VL	O	VL	O	O	O	O	O
C2	Governments supergrid integration policy		X	O	O	O	O	O	O	O	O	O	VH	VL	VL	VL	VL	VL	O	O	O	O	VH
C3	Supergrid business climate and conditions			X	O	O	O	O	O	O	O	O	VL	VH	VL	O	VL	O	O	O	O	VL	VL
C4	HVDC & HVAC electrification grid infrastructure				X	O	O	O	O	O	O	O	O	O	O	VH	O	O	O	O	O	O	O
C5	Land use, allocation and availability					X	O	O	O	O	O	O	O	O	VL	O	O	VH	O	VL	VL	VL	VL
C6	Geological conditions						X	O	O	O	O	O	O	O	O	O	O	VH	O	O	O	O	O
C7	Political, war, terror & security conditions							X	O	O	O	O	VH	VL	VL	O	VL	O	VL	VL	O	VL	VL
C8	Topographical conditions								X	O	O	O	O	O	O	O	O	VH	O	O	O	O	O
C9	Climatic conditions									X	O	O	O	O	O	O	O	VH	O	O	O	O	O
C10	Water availability conditions										X	O	O	O	O	O	VL	VH	O	O	VL	O	VL
C11	Natural disaster/hazard conditions											X	O	O	O	O	O	VH	O	O	O	O	O
C12	Political												X	O	O	O	O	O	O	O	O	O	O
C13	Economic													X	O	O	O	O	O	O	O	O	O
C14	Social														X	O	O	O	O	O	O	O	O
C15	Technological															X	O	O	O	O	O	O	O
C16	Legal																X	O	O	O	O	O	O
C17	Environmental																	X	O	O	O	O	O
C18	Ethics																		X	O	O	O	O
C19	Demographic																			X	O	O	O
C20	Ecological																				X	O	O
C21	Socio-cultural																					X	O
C22	Regulatory																						X

Fig. 5. Grey Structural Self Interaction Matrix on PEST of this study (ESM-9). NOTE: **O:** This factor has no relation/influence on the compared factor, when this factor is likened with the compared factor; **VL:** This factor has low influence on the compared factor, when this factor is likened with the compared factor; **VH:** This factor has high influence on the compared factor, when this factor is likened with the compared factor; **AL:** This compared factor has low influence on this factor, when this factor is likened with the compared factor; **AH:** This compared factor has high influence on this factor, when this factor is likened with the compared factor; **X:** These factors have relation on both of them.

Table 9
Number of factors at each investment stages (based on findings of this study).

Main stage name	Projects pre-development		Projects development	
Stage name	Preliminary screening	Screening	Pre-feasibility	Feasibility
Number of factors	11	Not in current study	191	Not in current study
Present research	Complex factor clustering by PEST extensions		Simple factors clustering only	
Future research	Complex factor clustering by PEST (final) Worldwide consistency & confidence Several evaluations Several expert decision makers		Complex factor clustering by PEST Several evaluations Several expert decision makers Worldwide consistency & confidence	

efficiencies in Refs. NREL SAM, 2015; RETScreen 4, 2015; Tamer et al., 2012; Luque and Hegedus, 2011).

Table 10
Awarded factors in preliminary screening stage.

No	Factor or criterion	Awarded status
C_1	Global Horizontal Irradiation (GHI)	Awarded
C_2	Governments supergrid integration policy	Awarded
C_3	Supergrid business climate and conditions	Awarded
C_4	HVDC & HVAC electrification grid infrastructure	Awarded
C_5	Land use, allocation and availability	Awarded
C_6	Geological conditions	Awarded
C_7	Political, war, terror & security conditions	Awarded
C_8	Topographical conditions	Awarded
C_9	Climatic conditions	Awarded
C_{10}	Water availability conditions	Awarded
C_{11}	Natural disaster/hazard conditions	Awarded

Finally, clustered structure was gathered as shown in Fig. 6 after application of complex factors clustering by Grey ISM MICMAC on PEST and its extensions clusters procedure in preliminary screening stage (Procedure 3), Main clusters (PEST and its extensions) in this study were found as Political, Economic, Technological, Environmental (ESM 9).

The short descriptions of awarded factors in preliminary screening stage were also made during this study as follows:

C_1: Global Horizontal Irradiation (GHI): Solar irradiance is the only resource behind this technology. Total irradiation that falls on PV panel surfaces generates electricity because of the valence band and the conduction band of semiconducting materials (Tamer et al., 2012). Photovoltaic systems have several mounting options such as fixed, tilted, 1-axis tracking, 2-axis tracking, azimuth tracking and their variations (Fig. 7). Hence, global tilted irradiance/irradiation (GTI) is the design aspect of PV plants.

Global horizontal irradiation (GHI), direct normal irradiation (DNI) can easily be deduced from the following expression:

$$GHI = DHI + DNI \times \cos(\theta) \quad (10)$$

where GHI: global horizontal irradiation; DHI: direct horizontal irradiation

C_2: Governments' supergrid integration policy (under Political): Engineering design of Supergrids and global grid can only be started by a common policy, framework and legislation. Common approaches should be organized by all governments.

C_3: Supergrid business climate and conditions (under Economic): International business organizations and creditors can only be built in safe, secure, and profitable business climate and conditions. International capital can be attracted under good conditions.

C_4: High Voltage Direct Current (HVDC) and High Voltage Alternating Current (HVAC) electrification grid infrastructure (under Technological): Technical electrical losses on transmission lines are a very critical issue for whole electrification system. Proximity to HVAC and HVDC transmission infrastructure is an advantage. Hence, infrastructure and expansion plans of HVAC and HVDC lines are a major issue during the location selection of new VLPVPPs in global grid and supergrid.

C_5: Land use, allocation and availability (under Environmental): The work of Ong et al. (2013), presented the land requirement for PV power stations of more than 20 MW, as approximately 24,000–40,500 m^2/MW (i.e. 6–10 acres/MW). As a result, an approximate size of land between 24,000 m^2–40,500 m^2, will be required for every MW of a VLPVPP.

C_7: Political, war, terror and security conditions (under Political): Supergrids and global grid are multinational and international electricity grids. These grids are to be designed for a very long time. Henceforth, safe and secure locations during engineering and construction periods shall be considered for evaluation and analysis. Moreover, the operational period is very important for the whole system. Unstable locations are not preferred during engineering, construction and operational periods.

C_8: Topographical conditions (under Environmental): Charabi and Gastli (2011), expressed that large-scale PV farms required flat terrain or fairly steep slope that are facing south with less than 5% graded slope.

Data and information for further understanding and evaluation of these factors can be gathered from several sources (Table 11).

Table 11
Some data and information sources of factors.

No	Title	Data & information source	Website address
1	Opinions	Experts (global & local)	
2	GHI data	3TIER	http://www.3tier.com/
3	GHI data	Saudi Arabia Solar Industry Association	http://saudi-sia.com/
4	High resolution photos	Panoramio	http://www.panoramio.com/
5	Satellite images	ImageSat® International	http://www.imagesatintl.com/
6	Satellite images	National Geographic	https://www.nationalgeographic.com/travel/lists/parks/national-parks-from-outer-space-aerial-photos/
7	Weather metadata	Earth Snapshot	http://www.eosnap.com/
8	Weather metadata	European Space Agency	http://www.esa.int/
9	Weather metadata	National Aeronautics and Space Administration	http://www.nasa.gov/
10	Weather metadata	National Oceanic and Atmospheric Administration	http://www.noaa.gov/

4. Discussion, conclusions and future work

In this research, location selection criteria of VLPVPPs in Supergrids (e.g. European Supergrid, American Supergrid, DESERTEC) and global grid concepts are identified, defined and selected for preliminary screening, and pre-feasibility investment stages. Eleven (11) criteria for preliminary screening, and 191 factors for pre-feasibility investment stages are presented to help solution of VLPVPPs' location selection problems in supergrids and global grid (ESM-10). These factors are studied in this research using 1GOAHIDSM according to N-grams principles in language model research field (N-gram is defined as a sequence of N words (e.g. 2-gram: two words in sequence, 3-gram: three words in sequence, 10-gram: ten words in sequence Jurafsky and Martin, 2009; Lin et al., 2012; Davies, 2016).

Location selection factors of VLPVPPs in supergrids and global grid concepts in preliminary screening investment stage are clustered by only one evaluation. Some of these factors (e.g. Global Horizontal Irradiation, HVDC and HVAC electrification grid infrastructure) may directly and commonly be used in preliminary screening, screening, pre-feasibility, and feasibility investment stages. Moreover, some of these factors (e.g. HVDC and HVAC electrification grid infrastructure, political, war, terror and security conditions etc.) may also be directly and commonly used for concentrated solar power (CSP), concentrated photovoltaic power (CPV) plants, and concentrated solar power–concentrated photovoltaic power (CSP–CPV) plants. Some of these factors (e.g. Global Horizontal Irradiation, Direct Normal Irradiance) may also be adopted for CSP, CPV, and CSP-CPV power plants.

This work contributes to RD^3&D efforts of PVPPs and VLPVPPs and their investments. These location selection criteria can be used for selecting and presenting best and publicly supported PVPPs and VLPVPPs locations (see Saracoglu, 2018, 2017f) (supporting by local and global people and investing by ordinary people). This study also contributes to RD^3&D of 1GOAHIDSM (see Saracoglu, 2016b), and further contributes to RD^3&D efforts of Global Grid Prediction Systems (G^2PS), Global Grid Electricity Demand Prediction System (G^2EDPS), and Global Grid Peak Power Prediction System (G^2P^3S) (see Saracoglu, 2017a,c,b,d,e), and including applications of fuzzy logic theory, Type-2 Mamdani FIS, grey theory, ISM, MICMAC, and PEST. Finally, it has contributed to applications of MCDM through the presentation of several preferable and useable criteria (see Saracoglu, 2016a,c, 2015a,c,b,d, 0000).

This research will hopefully be very helpful for academics, researchers, investors, governments and international organizations, to design and develop supergrids and global grid that will be needed to sustain 100% clean energy and zero percent emission environment. Further work should consider: (i) linguistic terms and scales, and should be studied in detail, (ii) weight assignments according to experts' experiences should be considered with detailed information from experts (see Ahmed-Kristensen et al., 2003; Jensen and Ahmed-Kristensen, 0000). Some of these factors will be vital during adaption to other investment stages.

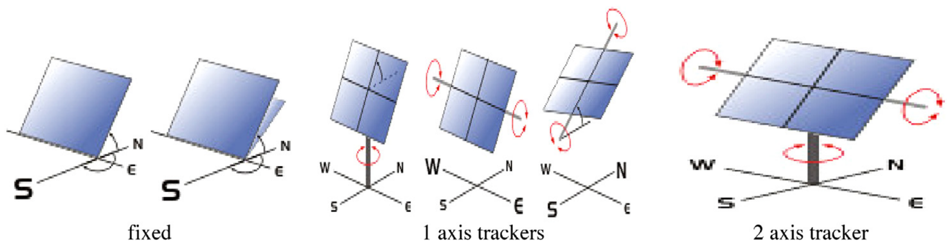


Fig. 7. Different PV mounting systems (credit and source: GeoModel Solar, 2015).

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.egyr.2018.09.002.

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