

SIMULATION OF SOLAR PANELS EFFECT ON THE MICROCLIMATE IN
ARID AREAS USING REMOTE SENSING TECHNOLOGY

Mohammed Ali Hakami

A project report submitted in fulfillment of the
requirements for the award of the degree of
Master of Science (Remote Sensing)

Faculty of Geoinformation Science and Engineering
Universiti Teknologi Malaysia

May 2009

To My beloved Parents, Brothers,,,

ACKNOWLEDGEMENT

First and foremost, I would like to express my utmost gratitude to my supervisor, Dr. Ali EL BATTAY for being a dedicated mentor as well as for his valuable and constructive suggestions that enabled this project to run smoothly.

Also, not forgetting Omar Molki and Ahmad Jabr, Dr. Salem M.Zaki and Dr. AbdulGaffar, I convey my full appreciation for their on-going support and contributions toward this project, whether directly or indirectly especially.

Last but not least, I am forever indebted to all my family members for their constant support throughout the entire duration of this project. Their words of encouragement never failed to keep me going even through the hardest time and it is here that I express my sincerest gratitude to them.

ABSTRACT

Using renewable energy sources become more significant than nonrenewable energy sources since it can reduce fossil energy consumption in an eco-friendly manner. Building solar panels in large area and use it as alternative energy may have significant effect on the microclimate. In this study, on some microclimate parameters effect have been studied extensively by measuring solar panels in field and laboratory experiments and integrating the results of these experiments through simulating in LANDSAT 7 ETM+ images of Riyadh - Saudi Arabia. The focus was on four microclimate parameters which are land surface albedo, land surface temperature, relative humidity, and atmospheric pressure. This study showed a clear impact when land cover changes to solar panel. In fact, the solar panel's albedo in the shortwave part of Electro Magnetic Spectrum (EMS) is around 0.13, compared to the dominant landcover class in arid area, sand which is 0.30. Furthermore, by implementing solar panels over a vast arid area, the surface temperature might increase by 20 – 30 % passing from an average of 45 °C to 62 °C. Thus, the relative humidity in the time of image has dropped from 13% standardize to only 3% in the case of solar panels. The fourth studied microclimate parameter, air pressure showed no significant change before and after simulation and seen more related to altitude.

ABSTRAK

Menggunakan sumber-sumber tenaga boleh diperbaharui menjadi lebih signifikan daripada sumber-sumber tenaga tidak boleh diperbaharui sejak ia boleh mengurangkan fosil penggunaan tenaga dalam satu eko mesra cara. Suria bangunan berpanel dalam kawasan luas dan menggunakan ia sebagai tenaga alternatif mungkin kesan pada mikroiklim. Microclimatic kesan-kesan telah dipelajari dengan meluas dengan mengukur panel suria di lapangan dan eksperimen makmal dan keputusan eksperimen-eksperimen ini adalah kemudiannya tersimulasi dengan LANDSAT 7 ETM imej-imej Riyadh - Arab Saudi dalam empat parameter mikroiklim termasuk permukaan tanah albedo, suhu permukaan tanah, kelembapan relatif, dan tekanan atmosfera. Rantau kajian ini menunjuk yang iaitu litupan tanah bertukar menjadi panel suria mempunyai kesan-kesan negatif pada mikroiklim. Albedo panel suria 0.13 terlibat atas kawasan kajian dengan bertambah suhu permukaan untuk 20 - 30 %, dan kesan suhu pada kelembapan relatif dengan berkurangnya nisbah daripada 13% untuk 3%, dan kesan itu juga pada tekanan udara tetapi adalah kesan rendah 2%.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	II
	DEDICATION	III
	ACKNOWLEDGEMENTS	IV
	ABSTRACT	V
	ABSTRAK	VI
	TABLE OF CONTENTS	VII
	LIST OF TABLES	XI
	LIST OF FIGURES	XIII
	LIST OF SYMBOLS	XVII
1	INTRODUCTION	
	1.1 Background	1
	1.2 Solar Energy, potential and challenges	3
	1.3 Problem statement	5
	1.4 Objectives	6
	1.5 Scope of this study	7
	1.6 Structure of this study	7
2	LITERATURE REVIEW	
	2.1 Introduction	8
	2.2 Desert	9
	2.2.1 Introduction	9

2.2.2 Desert microclimate	10
2.2.2.1 Vegetation	11
2.2.2.2 Substrate	11
2.2.2.3 Terrain elevation, Aspect and Slope	12
2.2.2.4 Water table depth	13
2.2.2.5 Proximity to coastlines	13
2.2.3 Desert Surface Energy Budgets	14
2.2.3.1 The basic of solar and terrestrial radiation Budgets	15
2.2.3.2 Surface radiation budget	16
2.2.3.3 Surface energy budget	17
2.2.3.4 Atmospheric component and surface energy budget	18
2.2 Photovoltaic (PV)	19
2.2.1 History of solar cell	19
2.2.2 First application of Silicon solar cell	20
2.2.3 Photovoltaic Technology	21
2.2.4 Solar panels energy mechanism	24
2.2.5 Photovoltaic performance	26
2.2.6 Temperature effect on Solar Panels	27
2.2.7 Solar Spectrum	28
2.3 Urban heat island	29
2.3.1 Surface UHI's	30
2.3.2 Atmosphere UHI's	30
2.3.3 Factors effect on urban areas	32
2.3.3.1 Reduced vegetation in urban area	32
2.3.3.2 Properties of urban materials	33
2.3.3.3 Urban geometry	34
2.3.3.4 Anthropogenic Heat	34
2.3.3.5 Weather	35
2.3.3.6 Geographic location	35
2.3.5 Increased energy consumption	36
2.3.6 Air pollutants and greenhouse gases	37

2.3.7 Health and comfort	37
2.3.8 Water quality	37
2.4 Summary	38
3 METHODOLOGY	
3.1 Introduction	39
3.2 Study area	30
3.2.1 Area description	40
3.2.2 Riyadh Climate	41
3.2.4 Study site area selection	41
3.2.4.1 Slope	42
3.2.4.2 Rainfall and elevation	43
3.2.4.3 Distance	44
3.3 The main framework of methodology	48
3.3.1 Satellite Data	50
3.3.1.1 LANDSAT ETM+ process stages	53
3.3.1.1.1 Atmospheric Correction	53
3.3.1.1.2 Landcover classification	54
3.3.2 Experimental data	56
3.3.2.1 Field Spectroradiometer	57
3.3.2.2 Thermal Camera	59
3.3.2.3 The Goniometer	60
3.3.2.4 Field and Lab measurements stages	60
3.3.3 Meteorological data	61
3.3.3.1 Accuracy Assessment	61
3.4 Microclimate's parameter	61
3.4.1 Land Surface Albedo	62
3.4.2 Land Surface Temperature	63
3.4.3 NDVI	66
3.4.4 Emissivity	66
3.4.5 Atmospheric Pressure	67
3.4.6 Relative Humidity	68
3.5 Summary	70

4	RESULTS AND DISCUSSION	
	4.1 Introduction	71
	4.2 Solar Panel Spectral Signatures in the field	71
	4.3 Solar Panel Spectral Signatures in the lab	77
	4.4 landcover change simulation	80
	4.4.1 Shortwave Albedo	84
	4.4.2 Solar panel effect on surface temperature (LST)	88
	4.4.3 Atmospheric pressure	95
	4.4.4 Relative Humidity	100
	4.5 Summery	102
5	CONCLUSION AND FUTURE WORK	
	5.1 Conclusion	103
	5.2 Future Works	104
	REFERENCES	105
	APPENDIX 1	109
	APPENDIX 2	114

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	The area of arid lands by continents (x 10 ⁶ km ²).	9
2.2	The vegetation covers of areas greater than 100 km ² and how that effect on other variables.	11
2.3	Photovoltaic cell and module technologies.	22
2.4	Summarize surface and atmospheric urban heat island.	31
2.5	Factors affects on urban heat island's.	35
3.1	The amount of solar panels needed to cover the kingdom.	47
3.2	LANDSAT ETM+ bands.	51
3.3	Details of the landsat data used in this study	51
3.4	SRTM data collection.	52
3.5	Landcover classification accuracy assessment.	56
3.6	Albedo values of desert in the great sahara and sinai deserts.	63
3.7	Gain of band6 in LANDSAT 7 ETM+.	64
3.8	Pre-launch calibration constants of thermal infrared band	65
4.1	Temperature (°c) of objects in the field.	74
4.2	Temperature (°c) of inner part and outer part of solar panel during morning till night in 05/03/2009.	75
4.3	Sun zenith angles of field area with frequency record every 30 min.	77

4.4	Sun zenith angles from LANDSAT ETM+ images for study area.	78
4.5	Solar panel spectral signature values from the field and the lab.	82
4.6	Albedo of both solar panels in the field on 5 may 2009.	85
4.7	Albedo of landcover elements in the image	86
4.8	An albedo of solar panels comparing with other landcover classes.	83
4.9	The influence of s.p.60 on landcover change (desert sand).	97
4.10	The influence of s.p.80 on landcover change (desert sand).	98

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	The fossil fuels become very vast and important	2
2.1	Middle east and north africa aridity	10
2.2	The differences between costal area and inland area in vapour pressure and air temperature.	13
2.3	The colors in the map show the local solar irradiance averaged over three years from 1991 to 1993 (24 hours a day).	14
2.4	The spectral distribution of radiant energy emitted from a black body at 6000k.	15
2.5	Atmospheric energy budget of the global annul average components.	18
2.6	The relation between cost and efficiency in three kind of solar panels.	23
2.7	Showing stages when solar panel work with high performance related temperature.	27
2.8	The air mass 1.5 spectrum compared to a 5700 k blackbody radiator	29
2.9	The differences in temperatures between surface and atmosphere. Where the temperatures in surface much more in atmosphere during the day.	31
2.10	Urban areas (a), which are characterized by 75%-100% impervious surfaces, have less surface moisture available for evapotranspiration(et) than natural ground	32

	cover, which has less than 10% impervious cover (b).	
2.11	The relationship between solar energy intensity and wavelength from 300 to 2600 nm.	33
3.1	Kingdom of saudi arabia and riyadh city	40
3.2	Slope image derive from SRTM images	42
3.3	Elevation data (meters) derive from SRTM images and cross sections a-b and c-d shows the elevated area and the main slope.	43
3.4	The rain rates of yearly rain from 1964 to 2001.	44
3.5	The total rain quantity from 1964 to 2001.	44
3.6	Flowchart represents the method to obtaining the area for plantation under gis environment.	45
3.7	Study area map showing the length from riyadh city around 60 km.	46
3.8	Landsat pixel 30m and including two proposed solar panels	47
3.9	The main flowchart	47
3.10	Figure 3.10 landsat image etm+ path 165 row 043, true color (r=3, g=2, b=1).	50
3.11	SRTM image showing height after fill gaps	52
3.12	The interference between urban and the rocks in the reflectance values in LANDSAT 7 ETM+.	54
3.13	Landcover classification process.	55
3.14	Classification map of study area.	53
3.15	Solar panel 60w (left) and solar panel 80.w (right).	57
3.16	Asd field spectroradiometer	58
3.17	Signature range using asd spectroradiometer.	58
3.18	Thermal image show the object's temperature at faculty of electrical engineering.	59
3.19	Sketch diagram of the goniometer.	60
3.20	Surface temperature work process from LANDSAT 7 ETM+.	64
3.21	The relation between the average of temperature and	68

	the relative humidity	
3.22	Saturation vapour pressure diagram	69
4.1	S.p's 80 installed in fke.	72
4.2	Spectral signature (reflectance) of solar panel 60w in two different time.	73
4.3	Reflectance data from field spectrometer in 05/03/2009.	76
4.4	Absorbance values from field spectrometer in 05/03/2009.	76
4.5	Temperature difference between solar panels faces.	72
4.6	S.p.60 spectral signatures in different zenith angles in the lab.	79
4.7	S.p.60 and sand spectral signature when light zenith angle at 8.60°.	79
4.8	The process to choose the spss for simulation.	81
4.9	Sand samples from landsat image (red point) and sand spectral signatures samples from the field in different times.	82
4.10	A. Study area showing the sand site without any change.	83
	B. Study area showing the field s.p.60 values in the site.	84
	C. Study area showing the field s.p.80 values in the site.	
4.11	A. Shortwave albedo map in 7-jul-1999	86
	B. Shortwave albedo map after simulation.	87
4.12	An albedo of solar panels comparing with other landcover classes.	87
4.13	The relation between air temperature and sand temperature.	88
4.14	The relation between air temperature and lst of sand in landsat images.	89
4.15	The relationship between the air temperature and the solar panels temperatures in the field	90
4.16	Relationship between inner panels and outer panels..	90
4.17	Simulated solar panels temperatures with sand	91

	temperatures samples from LANDSAT 7 ETM+.	
4.18	The temperatures difference of inner part of solar panels and sand sample.	86
4.19	Temperature map based on LANDSAT ETM+ on jan-2003 – before the simulation.	93
4.20	Temperature map based on LANDSAT ETM+ on jan-2003 – after the simulation.	93
4.21	Temperature map based on LANDSAT ETM+ on july-2002 – before the simulation.	94
4.22	Temperature map based on LANDSAT ETM+ on july-2002 – after the simulation.	94
4.23	Atmospheric pressure calculation using satellite data.	95
4.24	Atmospheric pressure map in 7-jul-1999.	96
4.25	Pressure map in jan-2003.	98
4.26	Pressure map in jan 2003 after the simulation.	98
4.27	Relative humidity map of study area.	100
2.28	Simulated relative humidity map of study area.	101
4.29	Relative humidity diagram.	102

LIST OF SYMBOLS

$^{\circ}\text{C}$	Calicoes degree.
$^{\circ}\text{K}$	Kelvin degree.
$3 \times 10^8 \text{ m s}^{-1}$	Light speed.
E_e	Emitted Energy.
ε	Emissivity.
σ	Steve Boltzmann $= 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
R	Net radiation.
μm	Micrometer.
α	Surface albedo.
$I \uparrow$	Outgoing long wave radiation from the surface.
$I \downarrow$	The absorbed downwelling long wave radiation.
ψ_{λ}	The transmissivity.
α_{λ}	The reflectivity.
ζ_{λ}	The absorptivity.
L	The latent heat of evaporation.
E	The evaporation or condensation rate.
H	The sensible heat exchange between the ground and the atmosphere.
G	The sensible heat exchange between the surface and the substrate.
W/m^2	Watt per square meter.
PV	Photovoltaic.
LEDs	Light-Emitting Diodes.
UHI	Urban Heat Island.
ET	Evapotranspiration.
SVF	Sky view factor.

SRTM	The Shuttle Radar Topography Mission.
ETM+	Enhanced Thematic Mapper plus.
NASA	National Aeronautics and Space Administration.
ATCOR	Atmospheric Correction.
LST	Land Surface Temperature.
TIR	Thermal Infrared.
K_1	$666.09 \text{ W/m}^2 \text{ sr } \mu\text{m}$.
K_2	1282.71 K.
AT.P	Atmospheric pressure.
DLR	GERMAN AEROSPACE CENTER.
Envi. dbase	Riyadh Environmental Data Base.
FKE	<i>Fakulti Kejuruteraan Elektrik – Faculty of Electric Engineering</i>

CHAPTER 1

INTRODUCTION

1.1 Background

The world is facing a global energetic crisis due to the overuse of Earth's non-renewable sources of energy such as fossil energy. Besides the scarcity of these resources, their use since the industrialized era has led to significant enhancement of the atmospheric greenhouse effect. Combined with other anthropogenic kinds of pollutions, it is obvious that the global warming phenomenon and the global climate change is a result of such blindly and uncontrolled overuse of Earth's fossil energy (Ferilli, 2009). the major problem of using fossil based energy is (i) it is not renewable, which means that after a certain time it will finish, and (ii) the global warming has reach an alarming level which shows a real danger to the future of all kind of life on the earth, including human being.

During hundreds of years, mankind has found a way to use fuel as a powerful energy source to produce electrical energy. Figure 1.1 indicates that the fossil fuels become highly significant. Heavy oils, oil sands and oil shale will increase the static lifetime to 62 years. Natural gas will last for approximately another 64 years,

whereas the reserves of coal will be available for about another 200 years (DLR, 2005). Uranium, another finite source of energy, will only last for another 40 years, using light-water reactors without conditioning the nuclear fuel. It would appear that there are considerable amounts of resources still available which in principal can also be used such as water and sun resources.

The distribution of energy resources among present and future generations is not ensured (DLR, 2005). Even if today's generation were to come to the conclusion that an appropriate basis for acting shall be left for future generations despite the exploitation of the reserves of fossil and nuclear energy carriers, then in the light of the long time needed to develop and introduce new energy technologies, the minimum requirement has to be to begin now to introduce forcefully these new technologies not dependent on using fossil or nuclear fuels and not to lay down any structures today which might make future changes impossible or impede changes significantly in this context.

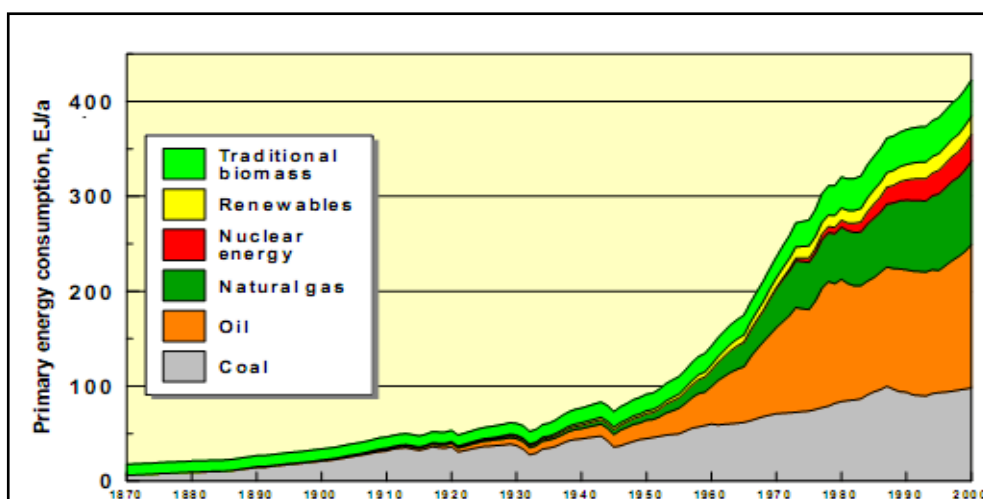


Figure 1.1 The fossil fuels become very vast and important (DLR, 2005).

To overcome this manmade dilemma, many alternative sources of energy have been studied, the main objective is to find an energy source which is renewable and Earth's friendly. Nuclear power, even if it is highly reliable, is no more a trend

because of its heating potential as well as the many political and geostrategic implications. In the last decade, a special attention has been given to other kind of energy's source, such as the hydropower, wind power, bio-fuel, geothermal energy, and last and not least, the solar power. In fact, it is proved that if adequate technology is developed and adopted, solar energy is enough to cover all modern societies' needs of energy (DLR, 2005).

In this study, the focus is on the solar energy issue and its impact on local and regional scale if exploited at a very wide level. Remote sensing capability is used to quantify the impact of the implementation of large solar plant, big enough to supply a modern megacity.

1.2 Solar Energy, potential and challenges

The solar energy is giving the earth heat through the atmosphere which absorbs the disadvantageous radiance (e.g. UV-C). It is the renewable source per excellence, because it is coming continuously from the sun. Wind energy origins from a non-homogeneous and variable warming up of the earth's surface by the sun (high and low pressure difference). Water energy, is the energy released by water in motion, again water cycle is made possible due to sun energy. The biomass energy is nothing else than solar energy, stored thanks to photosynthesis, in the plants green (vegetable) tissues (Ferilli, 2009). So, most of renewable and Earth's friendly sources of energy are related to the solar energy. However, solar technology means generally any kind of tool that allows the direct transformation of solar energy into forms of energy that are useful to man: heating, electricity, combustible. A famous solar technology is solar panels which are used to (I) transform directly solar radiance to electric energy, the so called photovoltaic solar panels, or (II) to convert sun light into heat which produce hot water and indirectly electricity, in this case it is called thermal solar panel.

Although the world now is talking about how to concentrate solar power to heat the water by technology called parabolic (thermal solar panel). Europe-Middle East & North Africa (EU-MENA) completed a study about the feasibility of Concentrating Solar Power to supply the Mediterranean Region (MED-CSP, 2005). This study confirmed the considerable potential of solar power, both photovoltaic and thermal, to produce the electricity and water supply of the whole region and all countries around the Mediterranean and the Arabian Peninsula. This project will reduce the CO₂ emissions and obviously contributes to decrease the global warming problem. Intergovernmental Panel for Climate Change (IPCC) recommends reducing CO₂ by 30% in 2050. MED-CSP summarized the study in the following statements (DLR, 2005):

- Environmental, economic and social sustainability in the energy sector can only be achieved with renewable energies. Present measures are insufficient to achieve that goal.
- A well balanced mix of renewable energy technologies can displace conventional peak-, intermediate and base load electricity and thus prolongs the global availability of fossil fuels for future generations in an environmentally compatible way.
- Renewable energy resources are plentiful and can cope with the growing demand of the EU-MENA region. The available resources are so vast that an additional supply of renewable energy to Central and Northern Europe is feasible.
- Renewable energies are the least cost option for energy and water security in EU-MENA.
- Renewable energies are the key for socio-economic development and for sustainable wealth in MENA, as they address both environmental and economical needs in a compatible way.
- Renewable energies and energy efficiency are the main pillars of environmental compatibility. They need initial public start-up investments but no long-term subsidies like fossil or nuclear energies.

- An adequate set of policy instruments must be established immediately to accelerate renewable energy deployment in the EU and MENA.

There are many suitable places which receive high amount of sun's energy over the world. For example, the Great Sahara in Africa is the largest area 9,064,960 km² and the yearly irradiance is around 260 W/m², the Empty Quarter in Middle East is the second larger area 2,589,910 km² where the irradiance is 270 W/m², while Takla Makan in china is the smaller area, 271,950 km², and a yearly irradiance of 210 W/m² (Bishop, 1991).

1.3 Problem statement

It is known; that any urban or rural area has its own microclimate which is a local atmospheric zone extending from 0.1m to 5 km, where the climate differs from the surrounding area. Many factors could affect the climate in local area such as water sites which are cooler than surrounding, the concrete or the asphalt which absorb sun's energy making the area hotter. The weather variables in a microclimate such as rainfall, wind, humidity or temperature, the natural surface like soil and vegetation and the local topography, all of these factors make the difference in the climate in local area.

The widely use of solar panel is related to the many advantages of this technology which has become one of the important element to produce economically electrical energy with no more pollution. However, installing solar panels in very vast area near to urban or rural sites could have a significant effect on human life and environment by modifying microclimate. For instance, considering a water vapour content of 5 grams per kg of dry air at 30°C, the relative humidity is around 16%, rising the air temperature by and additional 5°C, the RH become only 12% (Tetens,

1930). In fact, in arid and semiarid regions, adding a few centigrade degrees to a surface and/or air temperature which is at the top limit of tolerability (more than 50°C), that have a catastrophic impact on both flora and fauna.

1.4 Objectives

This project aims to simulate the impact of installing vast Photovoltaic solar panels plantation in arid areas and study the effect on the microclimate. The simulated site was selected near to Riyadh city in Kingdom of Saudi Arabia and the objectives of this project are as follows:

- (1) To extract solar panel spectral signature and to compare its albedo with other prominent landcover change in arid areas.
- (2) To use satellite imagery to choose the appropriated location to install imposing photovoltaic solar panels near Riyadh city.
- (3) To produce maps using satellite image of four microclimate's parameters, land surface albedo, land surface temperature, and relative humidity, before and after the simulated installation of photovoltaic solar plant.

1.5 Scope of the study

This study will focus on photovoltaic monocrystalline solar panels. The field study concerns two types of photovoltaics, the first produce 60W/h and the second produce 80W/h. For the simulation purpose, the desert and arid area near Riyadh city in Saudi Arabia has been chosen. LANDSAT 7 ETM+ images are used in this project because of its adequate spatial resolution, appropriate spectral coverage ranging from visible to thermal infrared and wide availability of free images covering many years. This project focuses only on four microclimates related parameters; land surface temperature, relative humidity pressure and albedo. SRTM images were used to extract elevation values of study area and Meteorological data to develop and validate the methodology. Spectroradiometer, Goniometer and other field instruments are used to extract solar panel spectral signature and PCI Geomatica, ERDAS imagine and ArcGIS are used to handle satellite images.

1.6 Structure of the document study

This report is divided into five chapters including this one. Next chapter is covering literature review of key elements addressed in this study, namely: Desert microclimate, Photovoltaic solar panel and urban heat island. In chapter three it is described the data sets (both images and ancillary), mainframe of the methodology to achieve the objectives and various processing models. Chapter 4 presents the results and discussion. Finally, the last chapter 5 presents the main conclusions and achievement of this study and some recommendation for future work.

REFERENCES

- Akbari, H. (2005). Energy Saving Potentials and Air Quality Benefits of Urban Heat Island Mitigation. *Solar Energy*.
- Algora, C. (2004). The importance of the very high concentration in the third-generation solar cells, *In Next Generation Photovoltaics*, A. Marti and A. Luque, eds., pp. 4025–4027. Institute of Physics Publishing, Bristol and Philadelphia.
- Bicheron, P, and M. Leroy (2000). Bidirectional reflectance distribution function signatures of major biomes observed from space, *Journal of Geophysical Research*, 105, 26669-26681.
- Carlson, D.E. (1995). Recent advances in photovoltaic's, *Proceedings of the 30th Intersociety Energy Conversion Engineering Conference*, ASME, pp. 621–626.
- Caforio-Ferilli. Solar Energy, Corso di fisica sperimentale. http://www.dimec.unisa.it/leonardo_new/ro/solar_energy.php.
- Gavin Schmidt, David Archer (2009). Climate change: Too much of a bad thing *Nature* **458**, 1117-1118.
- Green, M.A., Emery, K., Bocher, K., King, K.L., and Igari, S. (2006). Solar cell efficiency tables (version 27). *Progress in Photovoltaics: Research and Applications*, 14, 45–51.
- Gutman, G.G. (1989). The derivation of vegetation indices from AVHRR data, *International Journal of Remote Sensing*. 10, 107-132,.

- Hamakawa, Y. (2005). D.Y.Goswami and K.W.Boer, eds., In *Advances in Solar Energy*, Vol . 16, pp. C113–678. *American Solar Energy Society, Boulder, CO*.
- Jensen J. R. (2007). *Remote Sensing of the Environment An Earth Resource Perspective*. USA: Pearson Prentice Hall.
- J. K. B. Bishop and W. B. Rossow (1991). Spatial and temporal variability of global surface solar irradiance. *Journal of Geophysical Research*, 96, 16839-16858.
- Kalkstein, L.S. and S.C. Sheridan. (2003). The Impact of Heat Island Reduction Strategies on Health-Debilitating Oppressive Air Masses in Urban Areas. *Prepared for U.S. EPA Heat Island Reduction Initiative*.
- Kimes, D.S. (1983). Dynamics of directional reflectance factor distributions for vegetation canopies, *Applied Optics*. 22, 1364-1373.
- Liang S. (2004). *Quantitative Remote Sensing of Land Surfaces*. USA: WILEY-INTERSCIENCE.
- Press J. Perlin(2002). *From Space to Earth: The Story of Solar Electricity*. Cambridge, MA,: Harvard University Press.
- Sailor, D.J., and H. Fan. (2002). Modeling the Diurnal Variability of Effective Albedo for Cities. *Atmospheric Environment*. 36(4),713-725.
- Sailor, D.J. (2002). Urban Heat Islands, Opportunities and Challenges for Mitigation and Adaptation. *North American Urban Heat Island Summit*. 1-4 May 2002. Toronto, Canada.
- Saudi Aramco. (<http://www.saudiaramco.com>).
- Sun Angle Calculator (<http://susdesign.com/sunangle>).
- Tetens, O., (1930). *Uber einige meteorologische Begriffe*. *Zeitschrift fur Geophysik*. Vol. 6:297
- Taha, H. and L.S. Kalkstein, S.C.Sheridan, and E.Wong. (2004). The Potential of Urban Environmental Controls in Alleviating Heat-wave Health Effects in Five US Regions. *Presented at the American Meteorological Society Fifth Conference on Urban Environment*. 25 August.

Thomas T. Warner (2004). *Desert Meteorology*. Cambridge, MA,: Harvard University Press.

Voogt, J.A. and T.R. Oke. (2003). Thermal Remote Sensing of Urban Areas. *Remote Sensing of Environment*.