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An Environmental Simulation Model for the Assessment of Solar Energy Use in Cairo's Rapid Transit Networks

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Cairo's rapid transit networks are one of the main electrical transport means in the city that depend mainly on the traditional sources of energy. According to the energy and environmental world crisis, the research examines the potential use of regional solar energy by covering the first of Cairo's rapid transit networks with the solar system to substitute the traditional one. A three phase simulation modelling is proposed. The first phase is the ideal solar system (ISS) for evaluating the feasibility and efficiency of using the solar system. The second one is the solar energy reduction simulation model (SERSM) to be applied for the urban and environmental conditions. The proposed SERSM simulates the shadow cast within the environmental conditions on Cairo's rapid transit line representing the urban conditions according to the track aspect ratio. The third one conducts a detailed field survey for an action area for validating phase two results of solar energy reduction. The research shows the potentiality and the feasibility of using solar energy to substitute a portion of the used traditional energy sources of the rapid transit line, where a 34.5 km length can be covered. It is expected to produce about 7500 MWH monthly, equivalent to 50–60% of the electrical consumption of the line.

Keywords: environmental simulation model, shadow simulation, environmental information systems, solar energy use, greater Cairo metro.

Introduction

The trend towards the exploitation of renewable energy has become one of the most important global and local trends that aim to achieve sustainable development and contribute in alleviating the environmental problems caused by the excessive use of traditional energy sources. The seventh goal of the sustainable development goals set by the United Nations discusses the availability of a sustainable energy source that contributes to the promotion of economies, protection of ecosystems, equity and social justice (Nations, 2015). Moreover, the traditional energy sources are close to depletion, which requires seeking for other alternative sources of sustainable energy.

At the local level, Egypt seeks to improve its environmental status and achieve sustainable economic and social development, which requires the availability of adequate and regular sources of energy based on the local resources available at the local lands while ensuring the living conditions that are compatible with the population.

According to the characteristics of the Egyptian geographical location, Egypt has a huge renewable resource which is solar energy available all over the country. This resource, if exploited optimally, will satisfy Egypt's needs in the coming years of traditional energy. Egypt is one of the richest countries in solar radiation, where the Egyptian territory extends between 22 and 33 north latitudes, lying in the solar belt region, in addition to the dry climate and clear sky in most days all over the year. This weather helps to take advantage of solar energy as a renewable and environmentally clean energy. Studies show that the number of hours of solar brightness in Egypt ranges from about 2300 to 4000 hours per year, and that is considered to be one of the highest rates globally in solar brightness (NREA, 2013, 2015).

Recently, new technologies have been developed to facilitate the exploitation of the solar energy source to provide electricity in urban communities in various sectors aiming to use this renewable resource as an alternative to the traditional one.

There are numerous studies and researches that have discussed the applications of solar energy in green and sustainable transportation. The study of the BlackFriars Bridge's coverage in London, which is the limit of the most important bridges in the heart of London, is one of these studies that has dealt with the exploitation of solar energy on the different paths of traffic and covered by solar cells to generate clean electrical energy. This project was proposed to be the largest solar bridge in the world by covering this bridge with about 6.000 m^2 of solar cells generating about 900.000 kwh of electricity annually (National Authority for Tunnels (NAT), 2016).

The research aims to study the use of solar energy as one of the alternatives of renewable energy by covering the first line of Cairo's rapid transit networks by solar cells to substitute the traditional energy currently used, and to be one of the lead governmental projects.

Methods

The research examines the most effective line to apply the proposed solar energy system, which is a three phase simulation modelling to examine its performance and feasibility.

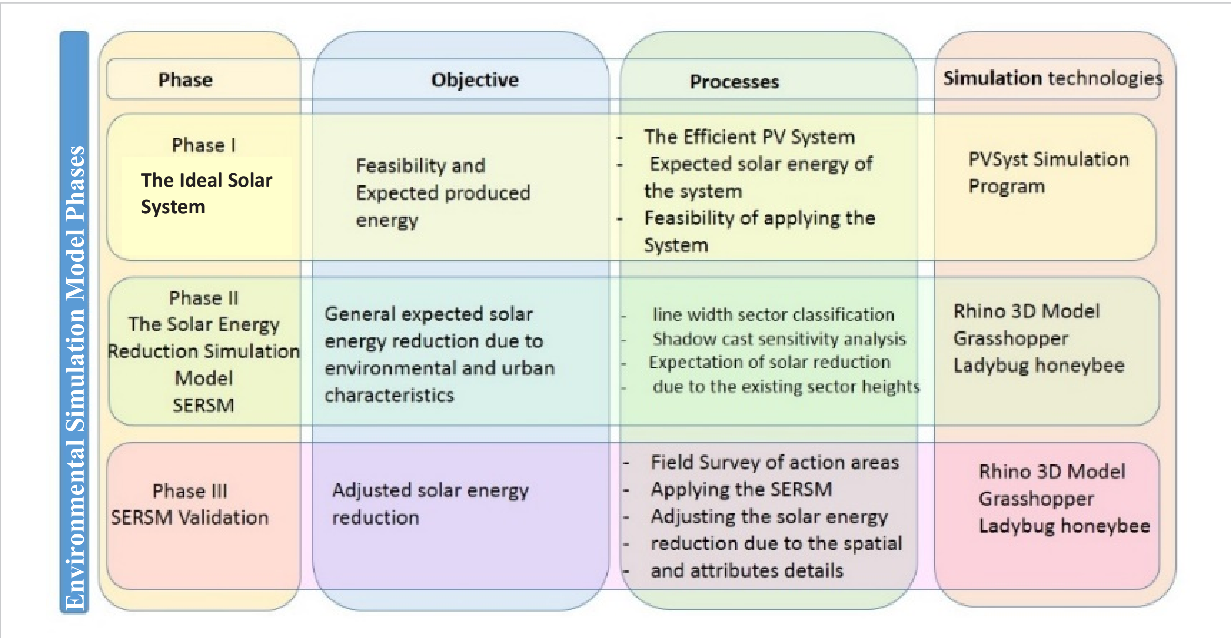
The ideal solar system (ISS) phase one aims to specify the optimum solar system for the project and to evaluate its performance for the rapid transit line by estimating the total amount of solar energy generated. The ISS simulation is done using the PVsyst modelling software.

The solar energy reduction simulation modelling (SERSM) phase two operates by a preliminary proposed simulation to predict the amount of reduction from the total solar energy generated according to the environmental conditions and the urban characteristics. The research applies the sensitivity analysis for the urban characteristics represented by the track aspect ratio. The sensitivity analysis is done by the simulation model using the Rhinoceros software package to perform a simulation for the shadow of buildings that has fallen on the rapid transit line using a 3D model of the track cross section based on the environmental parameters of the geographical location. The simulation package considers the geographic location for determining the environmental conditions such as solar radiation data, humidity, and cloudy areas, etc.

The third phase attempts to validate the results of phase two. The research reapplies the SERSM on the detailed action areas to compare the exact shadow simulation of an action area with the results of the proposed methodology for computing the solar reduction by applying the building height track width ratio using sensitivity analysis. The following diagram shows the methodological phases of the research:

Fig. 1

Research Simulation Modelling phases



Cairo's rapid transit lines overview

The rapid transit line in Egypt is considered the first line to be constructed in Africa and the Arabian Region. it is also considered one of the most important means of transportation in Cairo, as it serves about 3.6 million passengers per day. The subway works for 16.5 hours in winter (from 5:30 am to 12:00 am), and in summer it works for 17.5 hours (from 5:30 am to 1:00 am). Nowadays, the rapid transit lines are 3 lines connecting different spots of Greater Cairo, while it is planned to be six lines in the future ((IEA), 2006).

The first rapid transit line connects Helwan in the south with El-Marg in the north through a rail that reaches about 44.3 km, divided into 35 metro stations. All line stations and segments are uncovered (constructed above the ground), except five stations located downtown that are constructed underground with the total length of 4.7 km, while the total length of the uncovered stations and segments of this line is 39.6 km (National Authority for Tunnels (NAT), 2016).

The second rapid transit line connects El-Mounib in the south with Shobra in the north through a rail that reaches about 19 km, divided into 20 stations. Half of them are covered, while 10 stations are constructed under the ground with the total length of 9.5 km, while the total length of the uncovered stations and segments of this line is 9.5 km (National Authority for Tunnels (NAT), 2016).

The third rapid transit line moves through a rail reaching about 30 km, divided into 36 stations. This line is planned to start from El-Obour city until it reaches Cairo airport and then it is divided into two branches, the first or which reaches Embaba, while the second reaches Boulake. The phases one and two of this project have been accomplished; the first phase is from El-Attaba to El-Abbasia, and the second one connects Ard El-Maarad with El- Ahram (National Authority for Tunnels (NAT), 2016).

Plans of new rapid transit lines

The country is planning to construct three new rapid transit lines:

- the fourth rapid transit line will connect 6th of October city with El-Khosous;
- the fifth rapid transit line will connect El-Maadi with the Fifth assembly in New Cairo;
- the sixth rapid transit line will connect El-Amireya with the et-Tagamoa in New Cairo.

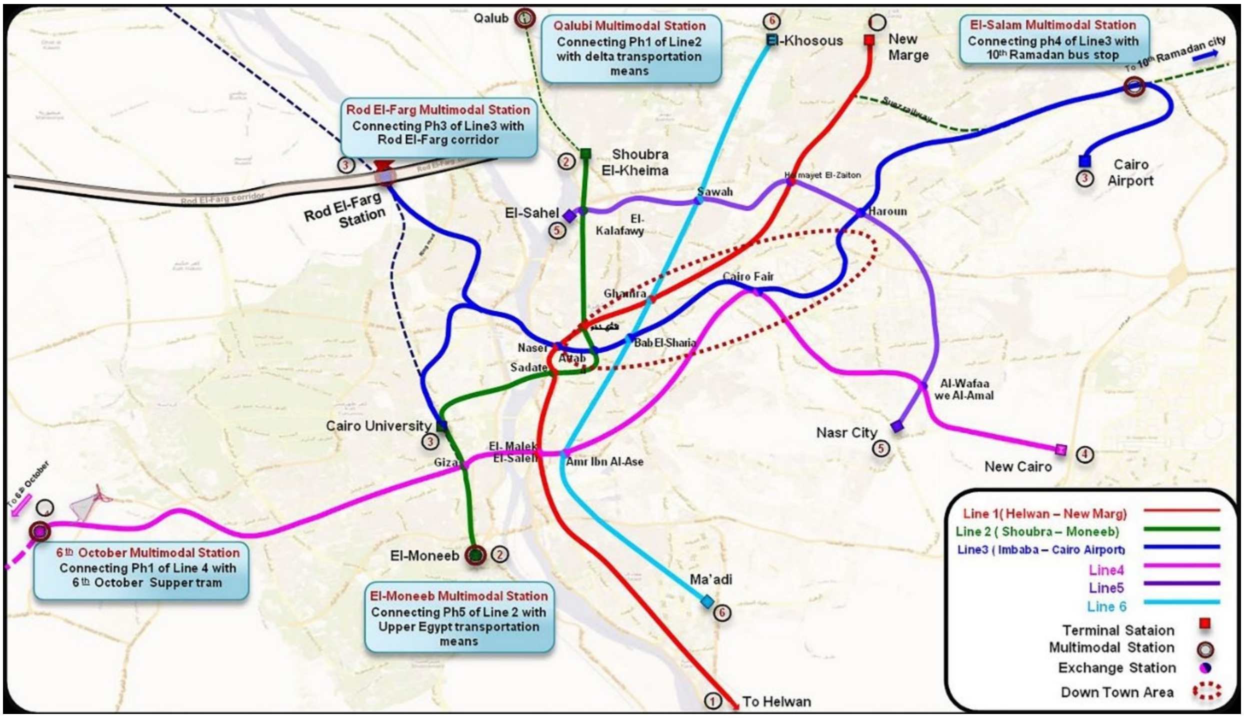
The research will focus on the first rapid transit line because most of its stations and segments are uncovered (constructed above the ground), with the total uncovered distance of 39.6 km. The following map shows the existing and the proposed Cairo's rapid transit line.

The rapid transit networks depend mainly on electricity in their daily operations, in terms of lightening of stations and tunnels, movement of metro cars, and chilling and mechanical ventilation.

The first rapid transit line utilises about 12.500 MWH monthly, while the second rapid transit line utilises about 19.000 MWH monthly, and the third rapid transit line utilises about 5.000 MWH monthly (NREA, 2013, 2015). The following figure shows the map of the existing and proposed Cairo's rapid transit lines.

Fig. 2

The map shows the existing and proposed rapid transit lines



Solar energy technologies

Egypt is a rich country of solar radiation all over the year. The simulation idea of this research is based on utilising this large time of exposing to solar radiation in generating electricity that can be used by the rapid transit network as a part of its consumption. Therefore, it is necessary to understand the technologies of solar energy to choose the subject that is most suitable for the research.

There are two types of solar technologies for converting to electricity: (1) photovoltaic (PV) and (2) thermal technologies (TT). The PV technology converts directly photons of the sunlight to electricity electrons by a PV cells which are integrated in photovoltaic panel units. Nowadays, solar panels convert most of the visible light spectrum and about half of the ultraviolet and infrared light spectrum to usable solar energy. The solar thermal power uses various means to generate heat, with the water being converted into steam to be used to drive a conventional steam turbine to generate electricity (FELIX A. FARRET, 2006). The PV systems are more adaptable and simple than the thermal systems, since they can generate power for many appliances, while the solar thermal is limited to space and water heating. The research proposes the use of the PV technology for the solar energy production (Amir Shahsavari, 2018).

PV solar cells types

Solar cells are simply semiconductor instruments that transfer sunlight into electricity through the photovoltaic effect. The purified silicon in different means is the most used substance in the manufacturing of photovoltaic solar cells.

Almost 90% of the world's photovoltaic systems are made of silicon. The silicon, used in PV, takes many forms. The main difference is the purity of silicon, as described below.

Mono crystalline silicon cells. Mono crystalline silicon cells consist of very fine layers of single crystalline that had been cut from cylindrical silicon ingots. The rounded silicon had to be cut in the polygonal shape to be easily compiled in modules. Mono crystalline silicon has a uniform generation attitude. Not only it has a careful, slow manufacturing process, but also it is the most expensive type of photovoltaic cells. Mono crystalline silicon cells can reach about 15–18% in efficiency, they are efficient, but there are some other technologies challenging it (Priscila Gonçalves Vasconcelos Sampaio, 2017).

Poly crystalline silicon cells. Polycrystalline (multi crystalline) cells are made of square silicon ingots. Molten silicon is cooled and solidified; however, they are cheaper in production than mono crystalline PV cells, but they are slightly lower in efficiency reaching about 13–16% (Priscila Gonçalves Vasconcelos Sampaio, 2017).

Thin film photovoltaic (PV) cells. These technologies minimise the usage of the materials that absorb sunlight to reduce the costs of the manufacturing process, but of course it is reflected on the efficiency which reaches a range between 6% and 12% on average (Hoda Akbaria, 2018). Thin film photovoltaic cells are formed of very thin layers of a semiconductor substance compiled by a backing material that may be glass, stainless steel or plastic. The commercially used materials are amorphous silicon (A-Si), cadmium telluride (Cd-Te), and copper – indium – (gallium) – dieseline (Ci (G) S). Thin film modules have lower manufacturing costs than crystalline cells. They also have a pleasant appearance, so they have the advantage to be used as a design element, but also they have a low rate of conversion of electricity. Thus, they need large areas and more materials (cables, support structures) to produce the needed amount of electrical energy.

Third generation solar cells. They are highly efficient PV cells based on new technologies such as:

- Thin film III-V solar cells: the manufacturing substances of this type are a combination between the third and the fifth group of the periodic table. The efficiency may reach from 20% to 25% (Hoda Akbaria, 2018). The most common manufacturing substance is gallium arsenide (Ga-As) that is mostly used in power supply of satellites.
- Multi-stack thin film: it depends on stacking III-V cells or silicon cells. The efficiency reaches up to 37%, and the individual cell absorbs a certain wave length, then the stack absorbs much more. It has a lot of names depending on the layer numbers (tandem, triple, or multiple cascade cells).
- Organic solar cells hybrid dye – sensitized solar cells: they depend on the usage of organic dye to absorb light. The cost efficient silk screen is used to offer a wide range of scopes for design like the one to be used in frontages or for advertising features. The efficiency ranges from 2% to 4% (Priscila Gonçalves Vasconcelos Sampaio, 2017).
- Fully organic solar cells: this type is at an early stage of development. It consists of hydrocarbon com-

pounds as well as a special electron structure, which is able to generate electricity. At present, the average cells efficiencies range from 3% to 5%. It still needs development because of its very short life span.

The research phase one simulation model attempts to use the most suitable PV cell type. It will simulate 1 km of the rapid transit line, in order to choose the most effective PV system and calculate the amount of electricity generated from the solar energy by the PV system.

Phase 1: ideal solar system (ISS)

The objective of phase one, for the proposed research simulation model, is studying the feasibility of using solar energy and choosing the ideal and effective solar energy system for covering the first line of Cairo's rapid transit networks.

In order to have the most effective use of solar radiation, the proposed PV system must be aligned to absorb and collect as much of the radiation as possible. The sun radiation's angle of incidence and the PV system parameters such as the tilt angle of the PV panels and the azimuth angle play the main role in achieving the greatest possible solar energy collected.

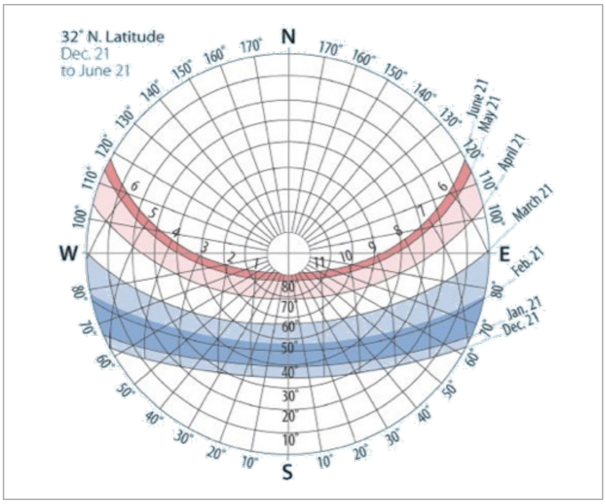
Cairo is located on the north hemisphere zone 36N. Understanding and studying the motion of the sun path is essential for proposing the ideal solar system type for a specific location as well as the value determination of the optimum PV modules installation parameters. The solar path is described with the sun path diagram known as the stereograph. The sun path stereograph depends mainly on the earth location and it shows the most important geometrical parameters, which describe earth-sun relations, include declination, sun height and solar azimuth. These parameters are shown on the stereographic sun path diagram for the sun's angle of the sun during the year for zone 36N (Fig. 3)

The efficiency of the solar energy system depends mainly on the used type of a PV system and its main installation parameters the azimuth direction and the tilt of the PV panels.

The azimuth angle of the PV modules specifies how many degrees the surface of the PV is from the exact south-facing direction. The tilt angle specifies the divergence from the horizontal. Previous studies and experiments show with respect to Cairo sun path that PV systems operate most effectively with an azimuth angle of about 0° and a tilt angle of about 30° (ROBAA., 2006) and the research will use these values for the proposed PV systems.

Fig. 3

Sun path stereograph for Cairo region



The simulation was applied on a randomly one kilometre length of the rapid transit line. The one kilometre chosen was between Ghamra station and El-Demerdash station, to compare the performance of the different PV system types with respect to the estimated electricity generated and the built up system cost. The research uses the PVsyst software for the simulation to compare the different PV system types and the expected generation of electricity and its percentage according to the total consumption of electricity by the rapid transit line taking into account the PV system cost.

The PVsyst is an energy modelling software for simulating the solar energy systems industry since the early 2000s. It has been widely regarded as the standard for bankable yield projections of commercial and utility scale of solar energy projects (SA, 2012). The PVsyst constructs a model for all types of PV systems with module and inverter parameters specific to the real products used on a particular project. The PVsyst is used to compare the performance of different PV systems, which depends mainly on the geographical location and the type of PV systems, and their installation parameters of azimuth and tilt of the PV modules. The PVsyst integrates simulation of the PV system with evaluation of its pre-feasibility, sizing and financial analysis, grid-connected or stand-alone. The software is not used to generate array layouts, neither to model shading from real obstructions. The research makes simple simulation of energy produced using the previous PV parameters as default for the simulation (Irwana, 2015).

The simulation has performed using the three main usable different technologies of the PV systems available in Egypt (mono crystalline, poly crystalline, thin film) in order to get a full vision about different results, and to have the ability to differentiate between technologies in terms of cost and efficiency. The following table shows the simulation final output for the three different technologies of the PV systems.

*** PV economic efficiency = cost for 1 km / energy output for 1 km**

Mono crystalline silicon cells are the most suitable type of photovoltaic cells for the usage in covering the line of Cairo's rapid transit networks because it is the most efficient cell type. As for the point of view of electrical generation, it has the highest rate among the deferent types. As for the point of view of economic cost, it has the lowest cost in generating 1 MWH among the deferent types, in addition to its availability in the Egyptian markets. Thus, the research proposed mono crystalline silicon PV cell type for the study.

Table 1

PVsyst simulation final output

	Mono Crystalline PV	Poly Crystalline PV	Thin film PV
1	2	3	4
Energy output for 1 km long MWH monthly	219	191.66	109.52
Total energy output MWH monthly	8674.2	7589.9	4337.1
Cost for 1 km (EUR)	641,821	581,849	400,040
Total cost (EUR)	25,416,111	23,041,220	15,841,584
Percentage of the consumption of electricity	69%	61%	35%
Economic efficiency of PV types (EUR/MWH)	2930	3035	3652

Fig. 4

Economic efficiency of PV types

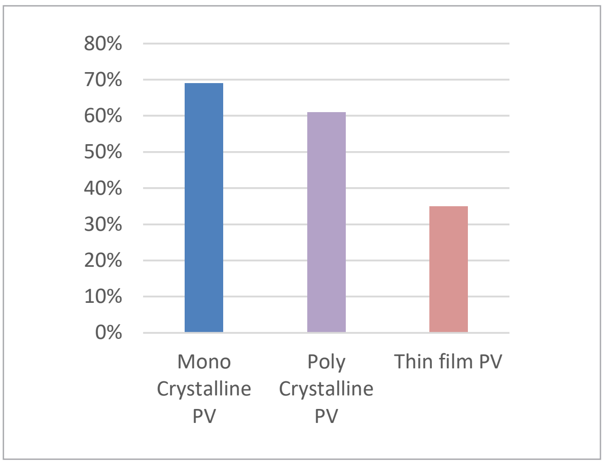
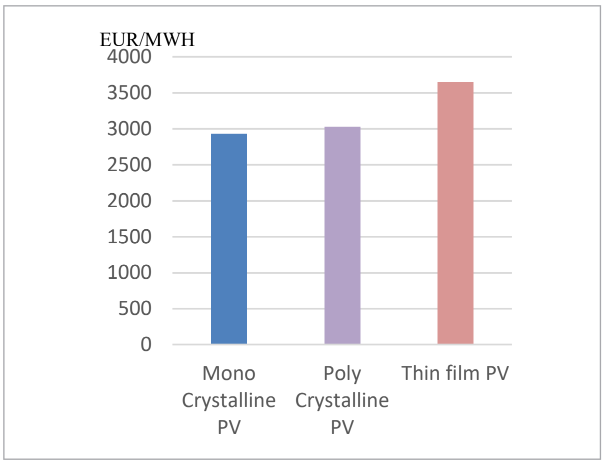


Fig. 5

Percentage of the consumption of electricity



Phase 2: solar energy reduction simulation model (SERSM)

The results of the ISS phase determine the optimum PV system and its installation characteristics of tilt and azimuth as well as the estimation of the total solar energy that might be produced. The estimated amount of the solar energy from the ISS simulation phase is affected and reduced mainly by the shadow of urban obstacle characteristics of the rapid transit line track and the spatial environmental conditions.

The two main environmental parameters affecting the solar energy are the sky cloud cover and the humidity, so they will be taken into account within the research simulation as shown in Table 2. On the other hand, the main urban factors affecting the geometric of shadow simulation are the track aspect ratio, which is defined as the ratio of the height of surrounding buildings and the right of way width of the rapid transit line. The track aspect ratio will affect the shadow simulation effect on PV cells by creating areas more prone to shade in different hours of solar brightness and other areas exposed to solar radiation in most hours of solar brightness.

The research proposed in phase two a preliminary solar energy reduction simulation model (SERSM) for computing the reduction effects due to urban and environmental conditions by applying an environmental shadow casting geometrical model for the rapid transit line region. Phase two started with the classification of the rapid transit line track with respect to the right of way track width and continued by applying a sensitivity analysis of the urban indicator, by determining the sun radiation obstacle represented in building height of surrounding building for each track width sector. The sensitivity analysis is done through simulating the dropped shadow model on PV cells taking into account the humidity and cloud cover as the environment conditions of the site. The sensitivity analysis is applied for each cross section width class by dropping a shadow model for a different building height for each cross section track width.

Table 2

The monthly, seasonal and annual mean of days of the sky cover occurrence (clear sky, c = 0 octas, partially cloudy sky, c = 1–5 octas and cloudy sky, c = 6–8 octas) over Cairo during the study period (1992–2003)

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Mean
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Clear sky	22	21	26	28	29	30	31	31	30	29	26	25	27
Cloudy sky	2	1	0	0	0	0	0	0	0	0	0	1	0
Partial cloudy sky	7	6	5	2	2	0	0	0	0	2	4	5	3

Season	Winter	Spring	Summer	Autumn
1	2	3	4	5
Clear sky	23	28	31	28
Cloudy sky	1	0	0	0
Partial cloudy sky	6	3	0	2

Rapid transit line width classification

The first line of the Cairo's rapid transit networks stretches from Helwanin the south to El-Marj al-Jadida in the north, consisting of 32 stations, including two underground stations and the remaining 30 stations are above the ground.

The research classified the rapid transit line into five main sectors according to the track width of the cross sections, shown in Fig. 6, are as follows:

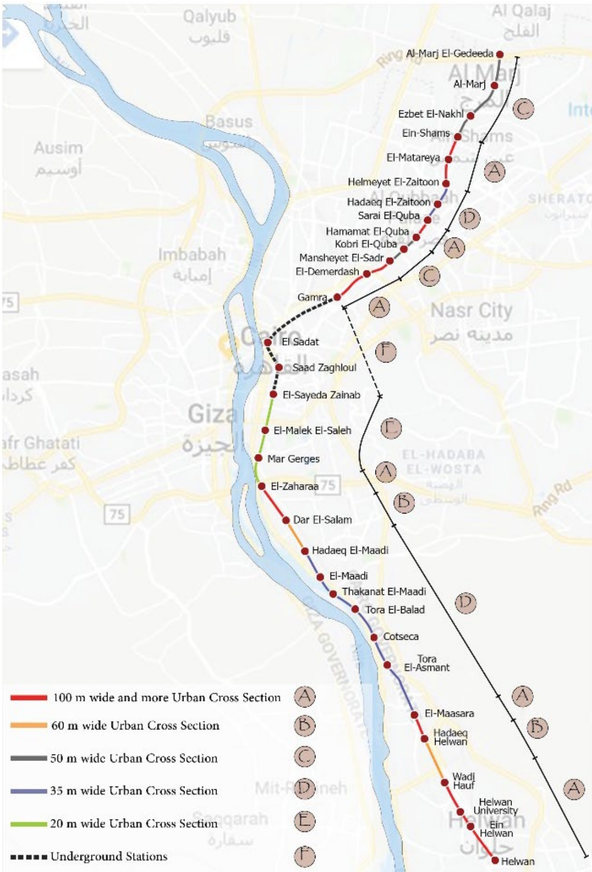
1. Sector A (100 m track width) with the total length 12.6 km;
2. Sector B (60 m track width) with the total length 4.8 km;
3. Sector C (50 m track width) with the total length 6.7 km;

4 Sector D (35m track width) with the total length 10.5 km;

5 Sector E (20 m track width) with the total length 5 km.

Fig. 6

Rapid transit line width track sectors



The sensitivity analysis of the track aspect ratio

The objective of the sensitivity analysis simulation, proposed by the research methodology, is to determine the critical height of different track sections, which will be considered as an obstacle for sun radiation and dropping shadow on the line. The result of this phase is a general view and an acceptable figure of the reduction percentage of solar energy according to urban and environmental characteristics without the need for a costly spatial field survey.

The research carried out the simulation for the different five track width sectors, locating the critical heights of the surrounding buildings on each side. The simulation was repeated with different surrounding building heights for each sector. For each simulation, the geometry of shadow cast was created by the buildings on the rapid transit line.

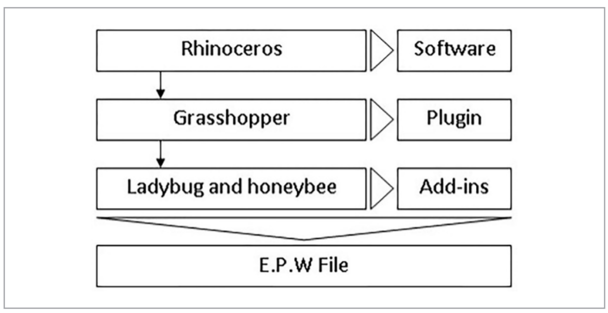
Architecture of the solar energy reduction simulation model (SERSM)

The research uses Rhino package to simulate shadow cast. Rhino is one of the best software for model designs and analysis of shadow. Rhino, or Rhino3D, is a 3D CAD modelling software package that enables accurate modelling of designs ready for shadow modelling, rendering, animation, drafting, engineering, analysis, and manufacturing (Ahmad Eltaweel, 2017). The simulation relied on the Rhinoceros software with the use of Grasshopper as a plugin for the Rhinoceros 3D modelling and the add-ins Ladybug and honey bee.

Grasshopper offers new ways to expand and control the 3D design and modelling processes, including automating repetitive processes, generating geometry through mathematical functions, quickly making changes to complex models, and creating complex forms through repetitions of simple geometry. On the other hand, Ladybug and Honey bee tools are a collection of free computer applications used within Grasshopper to support environmental design and to introduce the environmental conditions within the shadow simulation. Ladybug and honey bee tools are among the most comprehensive, connecting 3D computer-aided design (CAD) interfaces to a host of validated simulation engines for environmental conditions (Mostapha Sadeghipour Roudsari, August 26–28, 2013).

Fig. 7

Architecture of solar energy reduction simulation model (SERSM)



The Ladybug relied on an Energy Plus Weather Data file (EPW) containing data about solar radiation, temporal solar path, sky cloudy conditions and humidity using the UTM coordination of Cairo city, then draped and linked it to the 3D model of the rapid transit line region through Rhino (software), Grasshopper (plugin), Ladybug and Honey Bee (add-ins).

SERSM results

The simulation is done on one day of four different months to express the four seasons. The date was chosen on the 21st of the months (December, March, June and August), within 5 hours chosen in that day (6:00 am, 9:00 am, 12:00 pm, 3:00 pm, 6:00 pm).

The following figure shows an example of the output of the shadow simulation model for one sector throughout the 21st day in the four seasons in several hours of the day.

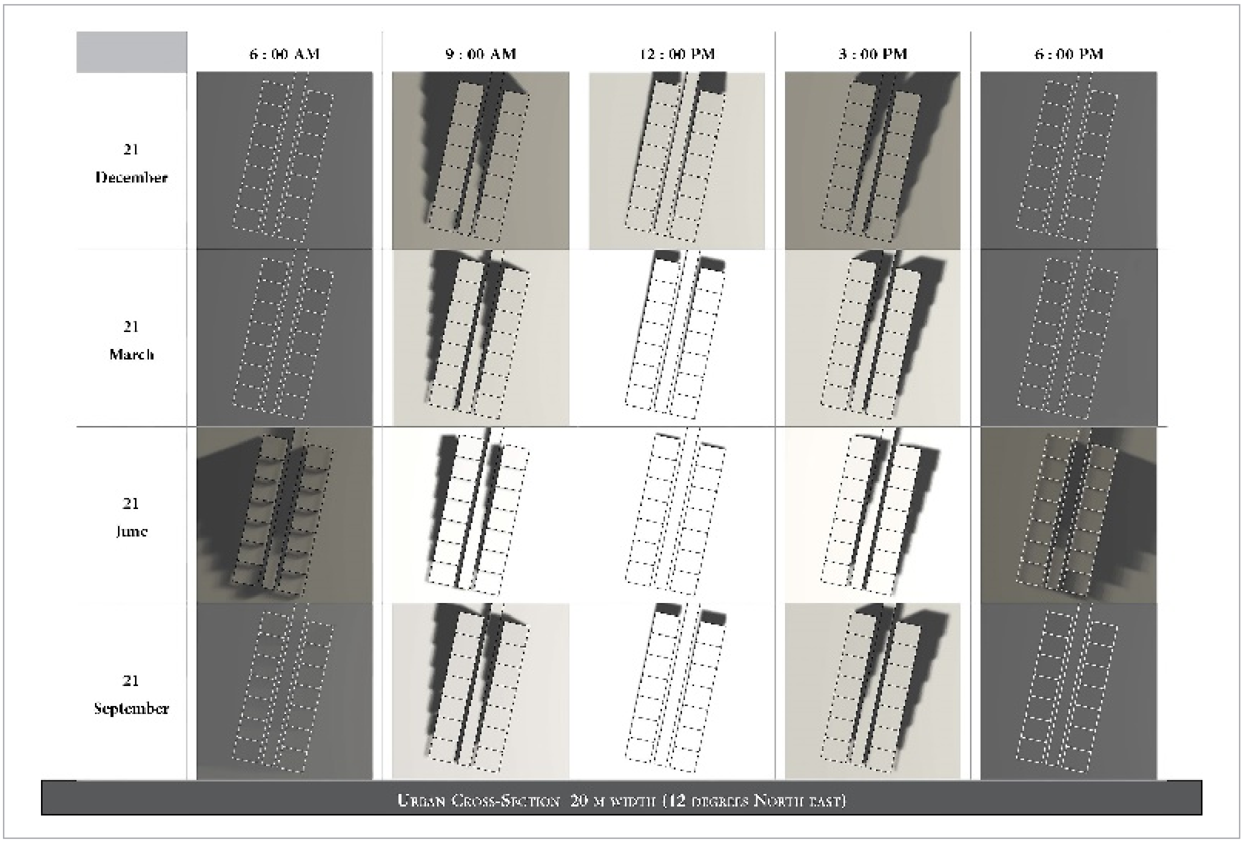
The preliminary shadow simulation for the sensitivity analysis of the track aspect ratio was done to determine the critical surrounding building heights, consuming time and money of a detailed field survey. The result of the sensitivity analysis is the minimum critical height for the surrounding building heights for each track width sectors to be considered as a sun obstacle and cast shadows on the rapid transit line will be created, preventing the solar cells from generating electricity and reducing solar energy.

Using secondary urban GIS data of Greater Cairo, the research estimated the existing percentage of building heights more than or equal to the critical heights to estimate the total percentage of shadow solar energy reduction for each rapid transit line class.

The SERSM was reapplied using the real percentage of critical building heights for same time and days for the SERSM.

Fig. 8

A sample of shadow simulation for one sector



The spatial and mathematical calculations of the SERSM output by adding and computing the percentage of the shadow track of the Rhino simulation results for different day time and different season, show that the total area might be excluded from photovoltaic coverage representing about 13% of the total exposed length of the first rapid transit line (its length is about 34.5 km), which can be covered with the photovoltaic cells without being shaded from the surrounding building.

The preliminary estimated amount of energy produced from it is about 7555.5 MWH monthly, which represents about 60.4% of the current electricity consumption of this line. Table 3 shows the results of the critical heights which will cause shadow of surrounding buildings for each track width sector. Table 3 also shows the percentage of the total track length and areas of each sector, which will be affected by shadow during the day and it will be mathematically excluded from solar energy produced from the PV system.

Phase 3: SERSM validation

The output of phase two is predicting the general amount of reduction on the estimated solar energy due to the environmental conditions and the urban characteristics.

Phase three attempts to validate the SERSM results. The research applies the SERSM on action areas by a detailed field survey of the track width and buildings heights to compare the real shadow reduction of action areas compared with the preliminary results of the sensitivity analysis of the track aspect ratio of phase two.

Table 3

Shadow sensitivity analysis simulation results

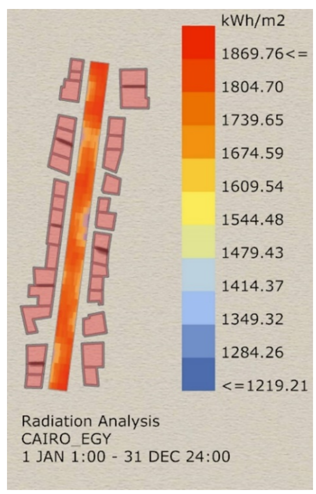
Sector	Sector length	Critical height	Existing building heights	% area shaded affected
1	2	3	4	5
A (100 m)	12.6 km	Above 10 floors	1–13 floors	12%
B (60 m)	4.8 km	Above 10 floors	1–6 floors	0%
C (50 m)	6.7 km	Above 10 floors	1–13 floors	25%
D (35 m)	10.5 km	Above 9 floors	1–13 floors	14%
E (20 m)	5 km	Above 6 floors	1–7 floors	5%
Total	39.6 km	Average Shadow area affected		13%

Fig. 9

Action area field survey for SERSM validation

Fig. 10

The solar brightness on the action area



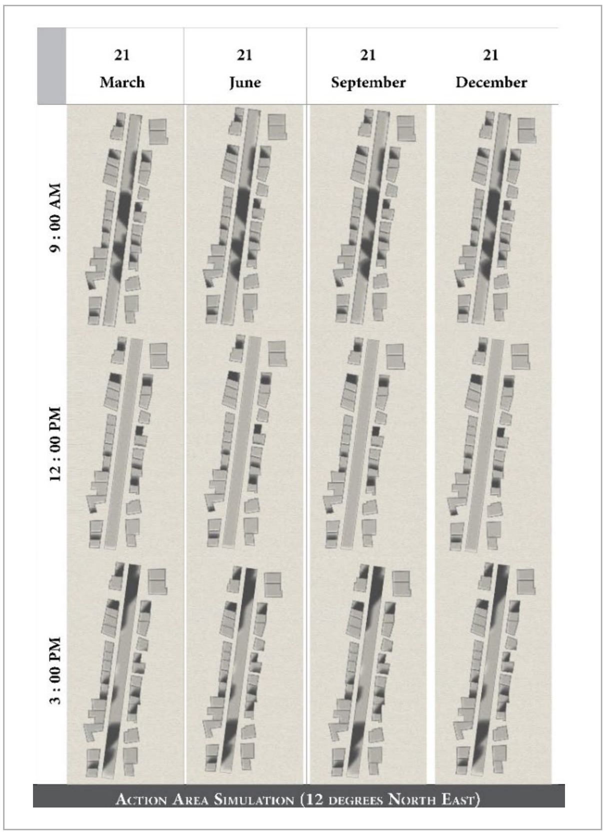
The research chose four action areas, distributed on each track cross section class affected by shadow. A detailed description for the detailed simulation of one action area with the highest building track width ratio on sector E with the 20 m track width, in addition to the diversity of building heights of above 6 floors in the section will be presented. The selected action area is located between Mari Gergis station and Elzahraa station. It was about 200 metre long on the line of the rapid transit. A field survey is conducted to characterise geometrically and the height attribute of each building of the action area; the map below shows the action area and the field survey building heights.

SERSM validation results

The simulation is done at the same time period chosen for the preliminary simulation: one day expressed for the four seasons. The date chosen is the 21st of the months (December, March, June and August), within three hours in that day (9:00 am, 12:00 pm, 3:00 pm,). By applying the above, the solar brightness on the action area (see Fig. 11).

Fig. 11

Action area simulation results



The detailed simulation results show the solar energy output of 43.8 MWH monthly for the action area, and the maximum percentage of shadow cast on the line area during the day was equivalent to 5.6% of the total study area. This percentage confirms the results of urban shadow studies, which have already determined the percentage of buildings excluded in the sector of 20 m, which is located in the study area about 5%.

The same simulation process for each of the four action areas is applied. The results show a range of difference in shadow reduction percentage from 10% to 22%, which might be acceptable for the study.

The research recommends to apply a detailed simulation for the whole track adding all obstacles, such as advertisement signs, stations and tracks of light structures in case of achieving accurate results.

Conclusions

The research proposed an environmental simulation model based on the environmental information systems for assessing the returns of solar system consumption within projects. The application of such a simulation model for Cairo's rapid transit networks indicated a necessity to provide clean renewable solar energy for generating electricity for Cairo metro throughout the hours of sunlight, which ranges from 8 to 10 hours a day in Cairo, and provide around 50% of the total energy required for the rapid transit line working hours.

The use of a photovoltaic system to cover 1 km of the Cairo's rapid transit networks line can provide 219 MWH monthly and cost around 2930 EUR for each one MWH. The estimated amount of energy is expected to be reduced because of the environmental and urban conditions, which was computed by the Cairo weather information system and the spatial shadow analysis of surrounding buildings on the rapid transit line. The simulation is done by excluding the metro sections exposed to the thrown shadow for a different time period. The simulation computation estimated the solar energy reduction by 13±5% of the total length of the line. The total length of the rapid transit line which can be covered is about 34.5 km and it is expected to produce about 7.555.5 MWH monthly, equivalent to around 50–60% of the electricity energy consumption of the line. It will save about 35% to 60% of required fossil fuel monthly by the first Cairo's rapid transit line. The replacement of clean renewable solar energy sources instead of the traditional electrical energy source shows a potential feasible source, which must be taken into account for big projects.

Until now, the solar energy technologies are characterised as highly costly and economically not suitable for the private sector. Despite the high initial installation and operational cost, solar energy can be seen as the future solution to the environment and energy crisis in Egypt. The use of alternative sustainable energy sources instead of the traditional ones has become an urgent issue to solve arising problems. Solar energy is a potential energy source in the Egyptian environment and must be well used to ensure the strategy of providing sustainable development projects.

The government should take the lead for such an environmental strategy by using such technologies for high consumption public projects, especially the electrical transportation projects, which are one of the highest big project energy consumption. The government must subsidise such environmental projects due to their high initial costs at the moment wishing to encourage the participation of private sectors in the field because of the expected long term profit economically, environment and social benefits of such strategy. On the other hand, the government must contribute, subsidise and support the solar energy technologies industry, which has started in Egypt for facing electricity problems

The environmental information systems and their simulation models are the state-of-the-art of the research for evaluating the use of solar energy. Such systems and models afford the opportunity to evaluate the different solar energy systems and their design strategies without committing expensive, time consuming resources necessary to implement the alternative strategies in the field. The used information systems and their simulation models allow us to compare and analyse the performance of different solar energy systems and alternatives quickly to avoid the risk, expense and disruption associated with extensive environment and field experimentation.

The environmental information systems and their modelling packages have become a new valuable environmental and analytical assessment tool. These information systems and their models have the capability of evaluating system performance within different environment conditions and provide the most detailed objective operational analysis technique available for evaluating the use of solar energy systems. Environmental information systems play a vital role in allowing the decision makers and researchers to evaluate complex solar energy projects within environmental and urban conditions that cannot be analysed directly with other means.

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