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# RAST: RoundAbout Solar Tracking

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**Abstract**

Roundabouts became popular worldwide as a tool to reduce the number of car accidents and the EU encourages and promotes this technology as a solution to the problems of urban and extra-urban traffic. RAST (Roundabout Solar Tracking) systems are designed to exploit the available space in roundabouts, which are already equipped and monitored, in order to produce electricity with a photovoltaic single axis tracking system. The energy produced can be used directly by the surrounding facilities or stored and consumed later or channelled to nearby car charge points. The amount of energy that can be produced on a single roundabout is limited by the land size and is normally in the range 100-400 kWp, but the number of suitable roundabouts in cities is high. Therefore, RAST could make an important contribution to the energy production.


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*Keywords:* photovoltaic; floating systems; tracking systems; roundabout

## 1. Introduction

The installed Photovoltaic (PV) capacity has increased rapidly in the last few years and in 2015 the PV market experienced a further worldwide expansion with an installed capacity of over 230 GW while the main development moved from Europe to Asia (China, Japan, India) and USA [1]. In particular, the strong exponential increase is driven by a reduction of PV system costs which for a utility scale system was about 1.8 $/Wp and it was estimated to range from 1.5 to 1.7 $/Wp in 2016 [2], [3]. The PV modules are emerging as a strong source of energy,

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which is efficient and distributed. The costs are decreasing and this justifies the effort to improve its use and to study the possibility of building large systems.

Two restrictions are still evident: the first is due to the availability of spaces for PV fields, the second is the cost of tracking systems, which would allow full use of the potential of the PV modulus, but have a higher cost and a more wide surface occupancy especially if we consider the double axis type (Fig.1 (a)). Therefore single, horizontal, North–South-oriented axis structures associated with flat-plate modules represent the most widely used tracking solution in current PV plants. Because of their inherent lack of shadowing in the North–South direction, single tracking devices can drive large surfaces and, owing to the horizontal axis position, associated wind loads tend to be relatively low. The structure involves a particularly simple and robust mechanical construction, which is the main advantage of this type of tracking.

However, the horizontal axis position limits the energy collected by the tracking surface. This depends on the solar climate and latitude of the site and can be compared with the energy collected by an ideal two-axis tracking, which represents the largest solar radiation potential for a particular location.

The major motivation for the development of other one-axis tracking alternatives is to overcome this limitation, while keeping the mechanics fairly simple. This type of single-axis tracker rotates around its vertical axis, in such a way that the azimuth of the receiver surface is always the same as the Sun’s azimuth, while its tilt angle remains constant. Progress has been made in systems with an axis, and RW Energy has proposed a solution for solar farms based on a rotating mono-block platform on the ground (Fig. 1(b)). Some results in [4] show that azimuth tracking represents an increase of about 10% in energy collection, in comparison with horizontal axis tracking. It can also be seen that the advantages of tracking energy increase for both latitude and clearness index. In [4] and [5] the theoretical aspects of the mutual shading among trackers is analyzed, by relating the collection of energy to the relevant design parameters, namely, the tilt angle and the aspect relation (length/width) of the single tracked surfaces, and the spacing between adjacent trackers in North–South and East–West directions respectively. The lower the spacing between adjacent trackers, the lower the gross land occupation (to this purpose the so called Ground Cover Ratio, GCR, can be defined as the ratio between PV array area and total ground area) and, therefore, the lower the land-area-related costs (land, civil works, wiring, etc.). On the other hand, the larger the impact of shadowing, the greater the detrimental effect is on the electricity generation of the PV plant. If the vertical axis tracking is applied to a PV array made of many rows, a tracking solution, named carousel, is realized. This solution can be applied for installation on a building roof, where solar trackers are needed of a size to fit on the roof with no roof penetration and with low profiles for low wind resistance.

This solution can be extended and adapted to a specific solution that we have analysed and patented: RAST.

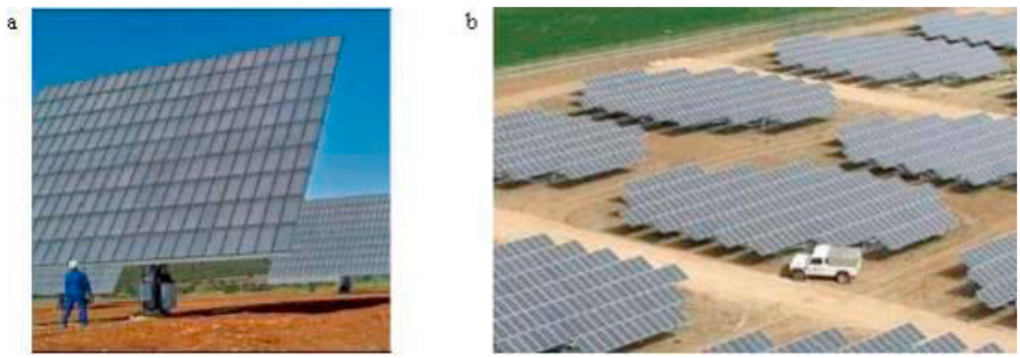


Figure 1 (a) Two axis tracking: Ammonix; (b) Vertical axis tracking: RW-Energy.

**2. 1. The RAST System**

RAST stands for Round About Solar Tracking and it aims to exploit available space, or at least already equipped and monitored locations, for producing electricity with vertical axis tracking PV systems.

The roundabouts, starting with the first solutions of the 90s in Australia, are emerging worldwide as a tool to break down the statistics on car accidents and Europe encourages and promotes this technique as a solution of the problems of urban and highway traffic.

These are mostly circular areas, with a diameter varying from 10 to 100 meters or more, which are sometimes transformed into green or decorative spaces. More often they host lampposts or telecommunication antennas and require monitoring and maintenance by local authorities.

The RAST system consists in equipping the roundabout with a rotating platform that houses the PV system. This presents a number of engineering and logistics advantages:

a) it use spaces otherwise left to decay or with not negligible maintenance cost; following [6] it can range from 4000 to 10,000 €/year depending on the roundabout size;
b) it integrates the urban and suburban policies for land management;
c) it is visible to the public, thus drastically reducing insurance costs, which are high for solar farms;
d) almost always there is already a grid connection because of the presence of lighting systems or of telecommunication antennas, however this does not preclude the use of a PV system;
e) it can provide a significant contribution to the national PV parks. In fact, 500 thousand km of Italian streets contain many roundabouts and nationwide the number is still rising. Therefore it is possible, with proper planning and intervening in thousands of large roundabouts, to raise the RAST parks to 1000 MW;
f) Figs. 2(a) and 2(b) illustrate the RAST project near Navacchio (Pisa, Italy). From the point of view of safety and resistance to atmospheric agents, the platform has characteristics of reliability and robustness comparable to those of a fixed installation on the ground.

The diameter of the roundabout is 80 m, but it was decided in this pilot plant to build just a 40 m diameter platform for a 100 kWp PV installation. It is worth noticing that the full utilization of the platform would house a 400 kWp system. The annual yield for a 100 kWp RAST system in Pisa is about 120,000 kWh /year, but, thanks to tracking, its yearly energy production will rise up to 150,000 kWh with an increasing of 25% compared to the fixed solution.

These values are naturally higher in Sicily. For example, in Catania (Italy), for the same installation without tracking, we get 145,000 kWh / year, rising to 185,000 kWh / year for the RAST system with a 28% increase if tracking is operative. As shown in Fig. 2(b), the system consists in three circular channels in cement on which the bearing structure, a kind of carousel, turns with an extremely slow movement. The PV modulus are inclined by 30° and suitably spaced to reduce the shadow effects. The circular rotation east-west is accomplished through an engine that acts directly on the wheels supporting the carousel. The presence of a central pole, quite frequent in the town for cell phone repeater antenna, gives rise to a shadow, which however can be easily managed. Actually the tracking system is such that shadows are projected always on the same position on the tracking platform, so that this part can be left free of PV modules and used for the managing and inspection of the structure.

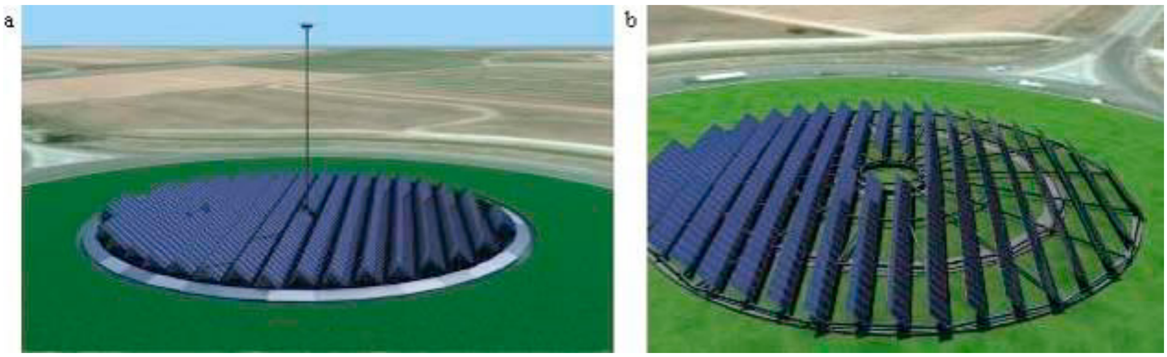

Figure 2 RAST in Navaccchio (Pisa, Italy): (a) rendering ; (b) ground based realization.

## 3. The floating RAST solution

The tracking mechanism constituted by rails and by the carousel is quite complex. A better solution, which improves the environmental acceptability, consists in creating a shallow large circular pool where a floating PV system with vertical axis tracking can be easily installed.
In Figure 3 and 4 a few renderings are shown which illustrate this solution. A rear reflector has been added in order to increase the energy harvesting. Furthermore, due to the presence of water, a cooling system can be easily implemented increasing the efficiency of the system by 10–15% [7]. A slightly different solution is proposed in Fig. 4 where the addition of a water jet is suggested both for technical purposes (cooling system) and for a more appealing urban integration.


Figure 3 Rendering of a floating solution of RAST.

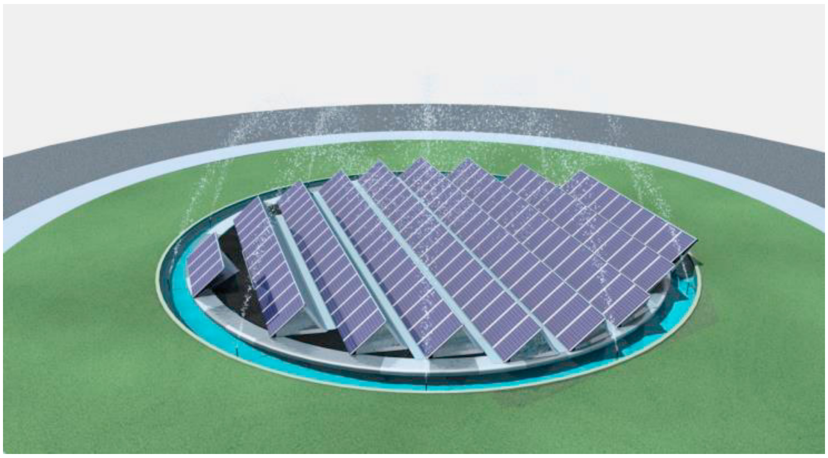

Figure 4 Rendering of floating RAST with a fountain

In Fig. 5 details of the tracking are shown with the automatic blocking system that every half hour puts the large platform in the right position, azimuthal tracking.
Several problems typical of a system with tracking are strongly simplified in the RAST system.

- The first is the grid connection, since all the roundabouts are usually equipped with a lightpole and most are grid connected. The frequent presence of a central pole, either for telecommunication or for monitoring and surveillance, does not obstruct the functioning of the rotating platform.

- The system supported by a turning carousel is mechanically simple, but rather expensive. The possibility to build a shallow water pool with a maximum depth of 40 cm solves several problems: the rotation mechanism is much simpler and cheaper and the water availability allows an economic cooling of the PV modules as well as the possibility of fountain effects with aesthetic benefits;
- The cost of the pool is low (we estimate it to 200 €/kWp) and is compensated by the greater energy harvesting due to the elimination of thermal drift.
- Reflectors can be positioned (see Fig. 5). Fig. 6 shows a feasible solution with V shaped reflectors.

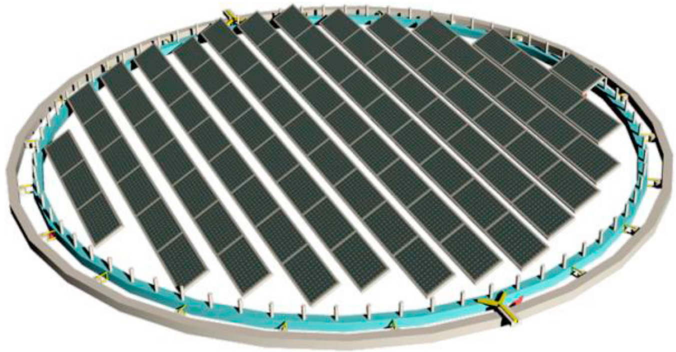

Figure 5 Tracking detail with rear reflectors

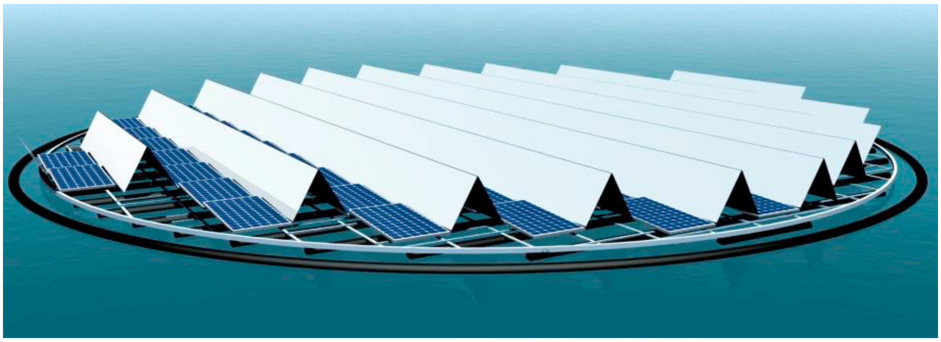

Figure 6 Floating platform with V shaped reflectors.

## 4. RAST solutions in Sicily (Italy)

In order to show the great number of possibilities existing everywhere, we analyse two typical situations in Sicily (Italy):

- the space of an urban junction in the city of Trapani (Fig. 8);
- a motorway junction at the airport of Catania (Fig. 9).

a b

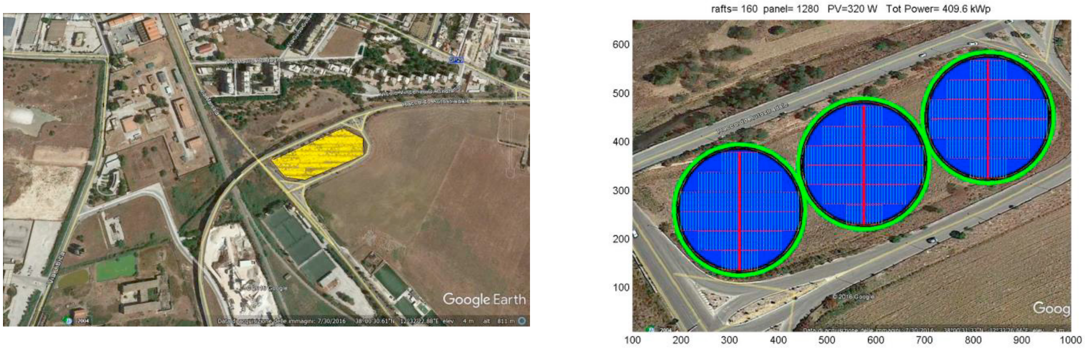


Figure 8 Trapani Via Marsala: three PV plants of 80 m. Power 1.6 MWp.

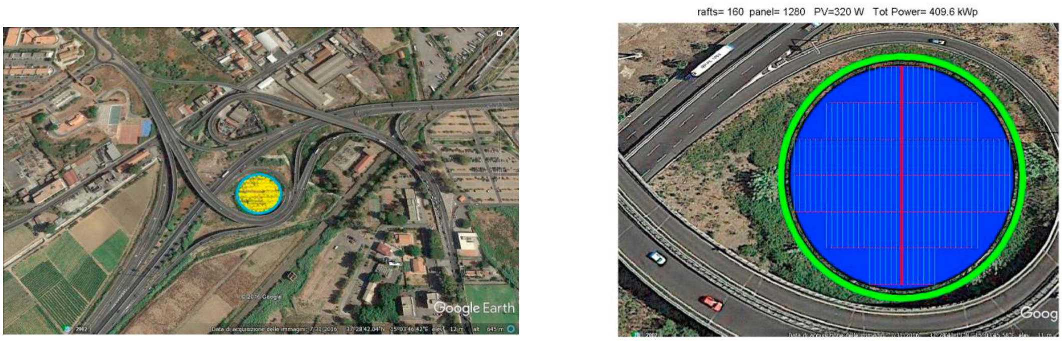


Figure 9. Catania airport Junction. Diameter 75 m power 400 kWp.

## 5. RAST solutions in Abu Dhabi

In order to show the potentiality of this solution, here we analyze a cloverleaf road very near Abu Dhabi airport road (8 km east of Abu Dhabi airport). In this case four floating plants could be installed, each with a diameter of 260 m, able to supply 1.6 MWp equivalent to a yearly production of approximately 12,000 MWh. As quoted in Fig. 10, each leaf of the cloverleaf is constituted by 792 rafts with 8 PV modulus per raft. The PV modules, being of 250 W each, generate a total power of 1584 kWp so that the full cloverleaf has an energy of 6.33 MWp and a yearly energy harvesting of 12,850 MWh and if cooling is active of almost 15,000 MWh. Many other possibilities like these exist and are suitable for an integrated solar energy production. Finally, a buffer zone of 5 m has been left in order to protect the PV plant from car accidents and in order to allow maintenance operations. plant.

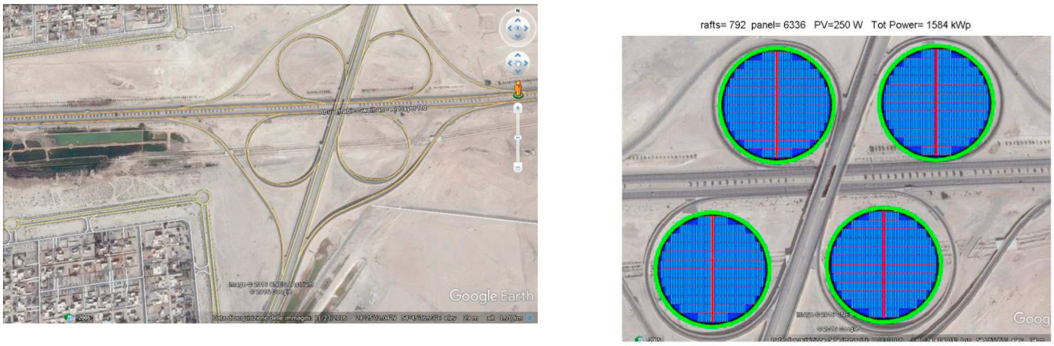


Figure 10 The cloverleaf on the road near the Abu Dhabi airport and Details of the floating tracking plant.

## 6. Security, tracking, cooling and evaporation

In general roundabouts are covered with grass, which requires a periodic maintenance, or with sculptures or fountains. The proposal of equipping many already existing structures with a PV plant with tracking is aimed to transforming a cost into an opportunity, without limiting the original use. Several aspects should be analyzed.

Safety: roundabouts are primarily a traffic facility and this function should not be altered. For this reason a buffer zone should be introduced and in all our schematic drawings a 5-meter strip of land has been left between the edge of the roundabout and the PV structure. The PV structure should eventually be protected but, especially if the floating solution is used, the containment pool will be in itself an adequate protection with a small wall of confinement.

Furthermore, lighting of the roundabout and monitoring cameras can be easily installed on a pole at the center of the structure in order to give information about traffic, accidents or willful tampering of the structure.

Tracking: the tracking system is quite simple from the mechanical point of view, the only problem being the cost of the structure and the energy required for the motion [7]. The tracking can be done as described in Fig. 1 by using a carousel or, alternatively, by creating a pool. The cost is essentially the same (200 € kWp), but the managing is quite different because the presence of water allows the cooling of modules but requires a different management.

Cooling and Evaporation: the presence of water allows the installation of a cooling system based on a water veil or on a sprinkler system. In the latter case, in an urban landscape, the presence of water jets can be an important aesthetic improvement. Furthermore, the presence of water allows the managing of green or flower zone at the edge of the roundabouts.

How much water do we need? In the absence of a cooling mechanism, the water consumption is limited. Even in a very hot zone, where the evaporation rate reaches 3 m/year, the evaporation is limited to 20-30 cm/year thanks to the almost complete coverage of the pool. This aspect has been analysed in [8]. In the presence of cooling this value rises to 50 cm. In terms of global consumption for a platform of 100 kWp (2,000 mq) this implies a consumption of 400 –1000 m3 / year which is a rather limited and sustainable request even in very dry regions. In the worst case, with a cost of 2 kWh per m3 of fresh water, this implies that 2000 kWh are needed in one year, compared to the full energy harvesting that for a platform of 100 kWp with tracking can reach the 200,000 kWh/y. If grass and flowers are not required, salty water can be used and this is always available at very low cost.

## 7. Cost analysis

It is not simple to evaluate the roundabout cost and different values are given. We have consulted Italian works [6], [8] and USA estimates [9] and what appears to be clear is that, neglecting the land cost (which in certain case can be very high), the cost of a roundabout with a 60 m diameter is around €500,000 (including the access streets) and its maintenance can cost

€10000 over a period of ten years. This cost scales linearly for larger roundabouts, whereas the smaller are more expensive.

In Table 1 we collect some data and we give the cost of the main items:

1 Two examples are chosen: a large roundabout of 60 m. and a huge one of 120 m. The kWp are respectively 100 and 600;
2 Pavement: this includes also works for changing the access viability;
3 Maintenance is an average of the 10 years cost for a standard medium size roundabout;
4 Pool or carousel: this gives the cost of the full structure supporting the PV modules. It is assumed that the roundabout already exists;
5 PV costs include all the items of the electric part: modules, cable, inverter, transformer and assembly;
6 Maintenance is the cost of the maintenance of the full roundabout including the PV modulus system;
7 Energy yield has been calculated for Sicily latitude and the value of 1820 kWh/kWp/y has been assumed;
8 Energy gain has been assumed to be 100 € / MWh and the gain has been calculate over a period of 10 years. This value depends on many parameters and mainly on the policy decision but this can be a reasonable estimate and the idea is to work in grid parity.

Table 1 shows that the cost for transforming a standard roundabout in a RAST system is limited (less than the construction of the roundabout) and that the investment has a return time of about 10 years.

Table 1 Cost for transforming a standard roundabout in a RAST system.

| Roundabout (diameter/PV power) | Pavement | Maint. 10 year | Pool or carousel | PV cost | Maint. 10 year | Energy yield | Energy gain |
|---|---|---|---|---|---|---|---|
| | € | € | € | € | € | MWh | € |
| 60 m /100 kWp | 500.000 | 100.000 | 150.000 | 80.000 | 50.000 | 1.820 | 182.000 |
| 120 m/600 kWp | 1.500.000 | 400.000 | 500.000 | 480.000 | 200.000 | 10.920 | 1.092.000 |

## 8. Conclusions

The possibility to equip roundabout structures with solar PV systems shows many advantages:

a) The use of the available area whose management is a cost for the community;
b) The simplicity of the structure, in particular if the floating solution is adopted;
c) The limited cost due to the fact that land is available, the pool construction is cheap and the maintenance limited, since water waste is strongly reduced by the strong reduction of evaporation;
d) The increase of energy harvesting due to the tracking and cooling mechanism, further increased by the possibility to introduce reflectors.

Other factors should be taken into account such as the proximity to the grid and the possibility to use the produced energy directly. However the first step would be a test phase in agreement with some municipalities in order to verify on the field the advantages and limits of this innovative proposal. The suggestion is to use large roundabouts, to take the maximum care of safety and to minimize the managing costs [10].

## 9. Bibliography

[1] "Annual report 2015, Report IEA PVPS," IEA International Energy Agency, 2015.

[2] WEB energy.gov/sunshot, "Photovoltaic System Pricing Trends," National Renewable Energy Laboratory NREL, 2015.

[3] BP Statistical Review of World Energy, "BP Energy Outlook," London, 2017.

[4] E. Lorenzo, M. Perez, A. Ezpeleta and A. J., "Design of Tracking Photovoltaic Systems with a Single Vertical Axis," *Prog. Photovolt: Res. Appl.,* vol. 10, pp. 533-543, 2002.

[5] L. Narvarte L, E. Lorenzo, "Tracking and ground cover ratio," Progress in Photovoltaics: Research and Applications 2008;16:703-14,.

[6] R. Mauro and M. Cattani, "Functional adn Economic Evaluations for Choosing Road Intersections Layout," *Traffic Managment Review ,* vol. 24, pp. 441-448, 2012.

[7] R. Cazzaniga, M. Rosa-Clot, P. Rosa-Clot and G. Tina, "Floating tracking cooling concentrating (FTCC) systems," in *38th IEEE Photovoltaic Specialists Conference (PVSC)*, Austin (USA), 2012.

[8] R. Cazzaniga, M. Cicu, M. Rosa-Clot, P. Rosa-Clot, G. Tina and C. Ventura†, "FloatingPhotovoltaic plants: performance analysis and design solutions," *Renewable & Sustainable Energy Reviews,* 2017 (under publication)

[9] LABORATORIO PER IL GOVERNO DELLA SICUREZZA STRADALE , "Le intersezioni a rotatoria, tecniche, costi, efficacia," 2010.

[10] U.S. Department of Transportation, "Benefit Cost Analysis Transportation Systems Management and Operations," Federal HighWay Adminsitration , 2009.