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USING SOLAR ENERGY IN AIRPORTS: THE POTENTIAL OF THE APPLICATION OF PHOTOVOLTAIC SYSTEMS

Ricardo Rüther
Professor at the Department of Civil Engineering at Universidade Federal de Santa Catarina
Labsolar – Laboratório de Energia Solar
Campus Universitário – Trindade
Florianópolis – SC – Brazil 88040-900
ruther@mbox1.ufsc.br

Priscila Braun
Master Degree Student of Civil Engineering at Universidade Federal de Santa Catarina
LabEEE – Laboratório de Eficiência Energética em Edificações
Campus Universitário – Trindade
Florianópolis – SC – Brazil 88040-900
priscilab@labeee.ufsc.br

ABSTRACT

Typically large, sunbathed and free of shading, airports have a great potential to the application of solar electric systems. Photovoltaic generators convert solar energy directly into electricity, with no moving parts, no gas or noise emissions, with very little maintenance and operating costs, using the inexhaustible power of the sun. The issue of the world's climate change due to the intensification of the greenhouse effect, caused by the emission of CO_2 and other gases deriving mainly from burning of fossil fuels, is closely related to air traffic. Air travel contributes considerably for global warming. Gas emissions by aircrafts are responsible for 3,5% of the global emissions of greenhouse gases, and this number is likely to double over the next 15 years. Projects that reduce or compensate for these emissions appear as stimulators of the carbon market. This paper aims at determining the potential of solar energy in airports in substitution of other polluting energy sources. The methodology used in the study includes the stages of obtaining information about the energy consumption and solar irradiation of airports; the assessment of photovoltaic generation in each Brazilian airport considering the application of the photovoltaic modules on rooftops, façades and grounds and the stage in which the results related to the potential of electricity generation are interpreted. The results show that the integration of photovoltaic systems to airports could meet the total energy demand for these buildings and also that, exchanging polluting energy sources by solar energy in airports would make possible negotiations in the international carbon market in the shape of credit bonds, reducing the emissions related to air travel.

KEY WORDS

Airport, solar energy, photovoltaic, CO_2 emissions, building-integrated, carbon market

CONFERENCE AREA

Project and Sustainability

INTRODUCTION

Nowadays the energy issue is a world-wide concern. Crises in the electric sector are becoming more and more common; the concern about the increasing scarcity of non-renewable natural energy resources, the necessity of increasing the reliability of the electrical system and the difficulties to finance and to implement large-scale energy projects are factors that lead to the search for new power sources.

One of the main problems generated by the use of fossil fuel as power sources is the environmental damage in the transformation, as much in local level, as in global level. One of the most powerful greenhouse gases is carbon dioxide, caused mainly by the burning of fossil fuels.

Despite the fact that it relies on mostly renewable (large hydro electricity plants) energy matrix Brazil is particularly privileged for having an average insolation level many industrialized nations', and has great potential for the use of solar energy. However, so far the country has been making very limited use of this potential, and a step forward to reverse this sub-use scenario is the SWERA (Solar and Wind Energy Resource Assessment) project, which is mapping the solar and wind potential of the Brazilian territory and 15 other countries. Preliminary results already indicate great solar and wind potentials throughout the country.

One example of the solar energy potential in the Brazilian territory is the island of Florianópolis: if its 424,4 km² area were completely covered by amorphous silicon photovoltaic modules (8% efficiency), we would have an annual production of 52,67TWh of energy. This figure corresponds to 238% of the total consumption by hydro-electrical and thermo-electrical generation by the entire state of Santa Catarina in 2004 (11,19TWh) (1).

The direct generation of electricity through the photovoltaic effect, one of the many uses of solar energy, is presented as one of the most rational ways to produce electric power. Using a renewable source of energy, the photovoltaic system turns the sun irradiation directly into electricity through a semiconductor material (silicon). Quiet and static, this promising technology of electricity generation provides the possibility of application at the consumption site or in a centralized form as in a conventional generating.

In the outdoor environment under the sun, rain, wind hail and all possible atmospheric conditions, photovoltaic modules are designed, developed and manufactured to be used in the harshest conditions, having demonstrated to operate in a satisfactorily for periods of 30 years or more. Therefore, they are appropriate for integration to the building envelope of the building, working as architectural elements and electricity generators.

Such characteristic makes the generation and energy consumption coincident, reducing losses in transmission and distribution, as well as the interconnection of the generating facility with the public electric grid, avoids the need for energy storage devices (battery banks), minimizing the high costs of investment and maintenance, as well as the environmental impact associated to the chemical accumulators.

Photovoltaic solar systems are becoming more and more popular not only for residential use but also in commercial, industrial and public buildings where there is a time coincidence between generated solar energy and energetic demand due to the use of equipments and air conditioning systems. Figure 1 shows an example of integration of photovoltaic modules to the building's architecture.


Figure 1: Building integration of PV to the Devonshire building – UK. (2)

The Universidade Federal de Santa Catarina has been experimenting with photovoltaic systems since 1997, acquiring data in electric energy generation through photovoltaic installations in different areas in Brazil. Based on these systems, this study-case will simulate the integration of photovoltaic systems to Brazilian airports, considering mainly the integration of these modules on the buildings' envelope, aiming at maximizing the application of grid-connected photovoltaic systems to the public electricity grid.
The first grid-connected photovoltaic system integrated to a building in Brazil was installed in 1997 by LABSOLAR (Laboratorio de Energia Solar), which has specialized in grid-connect installations, observing its operation and maintenance characteristics in places with generation systems all over the country. With a 2kWp power, comprised of amorphous silicon photovoltaic modules and approximately 40m², the system is fully-monitored, with solar radiation, temperature and electric parameters sensors which are measured every four minutes (3). According to this experiment, many others grid-connect systems have been installed around the country, adding more experience and performance data.
Analyzing the use of a renewable energy source to compensate the green house gas emissions caused by air travel, this project aims at determining the potential of the use of solar energy in airports as a substitute for other pollutant energy sources.

COST-RELATED CONSIDERATIONS

Nowadays the cost of photovoltaic solar cells is a great challenge for the industry and one of the main obstacles for the widespread diffusion of this technology. The photovoltaic technology is becoming more competitive because its costs are decreasing (4), and because the evaluation of the costs of the other forms of generation is becoming more realistic, taking into consideration externality factors that used to be ignored, as the environmental impact issue.
The use of photovoltaic solar energy has been growing in a fast pace in recent years. During the 90s, the market has grown at a 20% per year rate and, between 2000 and 2005, this rate was over 40%. (Figure 2).

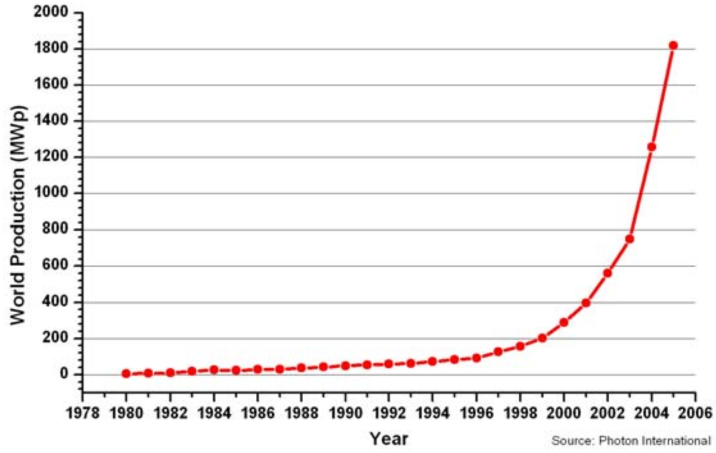

Figure 2: Annual world production of photovoltaic modules including all technologies. (5)

Nowadays, the world production of photovoltaic modules is over 1800MW per year, basically due to the expansion of the residential grid-connected installations, with system cost of about US$ 6/Wp and reduction perspective of US$ 3/Wp for the next five years (6).
Figure 3 shows the evolution of the share of grid-connected systems in the photovoltaic market. Grid-connected applications have recently experienced rapid growth due to the increased reliability and cost savings associated with the incentive programs, specially the ones from the German, Japanese, Spanish and North American governments, conceived to increase the generation of electricity by renewable sources and reduce the emissions of greenhouse gas effects.

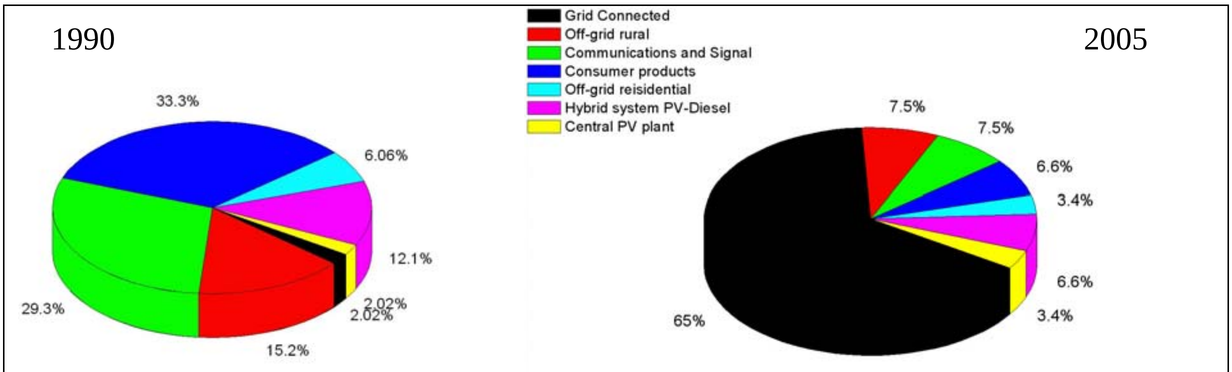

Figure 3: Photovoltaic market share (7)

The cost of energy produced by photovoltaic systems nowadays is still too high compared with the conventional energy generated by hydro, thermal, or nuclear sources. which represents a strong obstacle to its popularization. A strong counter-argument to the high costs of photovoltaic-generated energy is the observation of the learning curve of the photovoltaic technology, which has been showing a substantial cost reduction for terrestrial applications since 1970 (8).

BUILDING-INTEGRATION ISSUES

Airport buildings are usually large and horizontal, free of shading; they usually present large flat areas; their façades and the roofs can perfectly accommodate the photovoltaic modules.

For such characteristics, airports appear as having a great potential for the application of these systems. Figure 4 shows in detail the possibility of the *brise* area for the installation of photovoltaic modules.

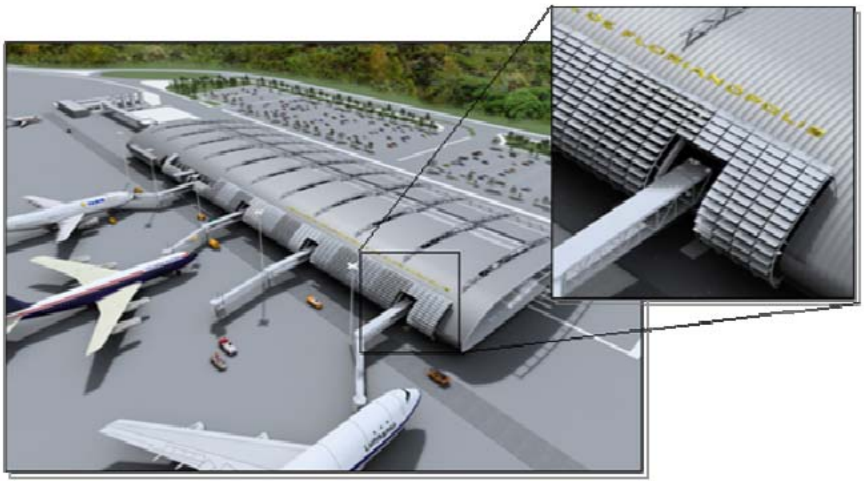

Figure 4: The new international airport of Florianópolis. Source: INFRAERO

Airport ground areas are typically large enough to accommodate isolated arrangements that can be used in some cases as sound barriers against the noise produced by aircrafts, deflecting noise from the passenger terminals. Such area can be used for building the systems, which would make the photovoltaic array more versatile in terms of tilt and orientation. Figure 5 shows the one of the largest installations so far (photovoltaic installation of 1,4MWp, with an area of 40.00m² and 9.200 modules operating since January 2004); however, the restrictions imposed by regulatory bodies concerning proximity to the lanes must be analyzed.

Figure 5: Saarbrücken Airport (Germany) (9)

Airport buildings are examples of ideal application of photovoltaic systems connected to the grid, where peaks of solar generation and consumption frequently happen at the same time because of the use of air-conditioning systems. The relation between solar generation and energy consumption contributes to the viability of grid-connected photovoltaic systems, since the investment can be considered as a postponement in the upgrading of transmission lines, substations and other equipment for the increase of the supply of electric energy to the grid where there is need of expansion.

THE AVIATION INDUSTRY AND THE ENVIRONMENT

The increase in the use of air transportation in the last years has put airports all over the world in constant expansion and modernization to accommodate the increasing demand. The recent launching of the new aircraft of the company Airbus, the A380, consolidates this trend. Virtually, "half of the world" travels by airplane every year (3,9 billion de passengers in 2004 - (10)), including many of the decision makers, as politicians and businessmen. This makes the airports a perfect space to spread out the photovoltaic technology to society and also become more competitive due to volumes of scale. Furthermore, it can also be a way to mitigate damages caused by air travel emissions. Table 1 shows the 30 busiest ACI (Airports Council International) registered airports worldwide in 2005, and the annual growth in passenger numbers from 2004.

Table 1: Top 30 Airports in passenger numbers

Rank	City (Airport)	Total Passengers	% Change
1	ATLANTA, GA (ATL)	85 907 423	2.8
2	CHICAGO, IL (ORD)	76 510 003	1.3
3	LONDON, GB (LHR)	67 915 389	0.8
4	TOKYO, JP (HND)	63 282 219	1.6
5	LOS ANGELES, CA (LAX)	61 485 269	1.3
6	DALLAS/FT WORTH AIRPORT, TX (DFW)	59 064 360	(0.6)
7	PARIS, FR (CDG)	53 756 200	4.9
8	FRANKFURT, DE (FRA)	52 219 412	2.2
9	LAS VEGAS, NV (LAS)	44 280 190	6.8
10	AMSTERDAM, NL (AMS)	44 163 098	3.8
11	DENVER, CO (DEN)	43 307 335	2.2
12	MADRID, ES (MAD)	41 939 904	8.4
13	PHOENIX, AZ (PHX)	41 204 071	4.3
14	BEIJING, CN (PEK)	40 989 651	17.5
15	NEW YORK, NY (JFK)	40 584 001	8.2
16	HONG KONG, CN (HKG)	40 282 000	9.7
17	HOUSTON, TX (IAH)	39 713 920	8.8
18	BANGKOK, TH (BKK)	38 985 043	2.7
19	MINNEAPOLIS/ST PAUL, MN (MSP)	37 563 664	2.3
20	DETROIT, MI (DTW)	36 374 906	3.4
21	ORLANDO, FL (MCO)	33 907 396	8.4
22	SAN FRANCISCO, CA (SFO)	33 580 662	2.6
23	NEWARK, NJ (EWR)	33 033 569	3.6
24	LONDON, GB (LGW)	32 784 177	4.2
25	SINGAPORE, SG (SIN)	32 430 856	6.8
26	TOKYO, JP (NRT)	31 525 275	1.5
27	PHILADELPHIA, PA (PHL)	31 502 855	10.5
28	MIAMI, FL (MIA)	31 008 453	2.8
29	TORONTO, ON, CA (YYZ)	29 914 925	4.6
30	SEATTLE/TACOMA, WA (SEA)	29 289 009	1.7

Source: Airports Council International - ACI (10)

The issue of the global climate change derived from the intensification of the greenhouse effect, caused by carbon dioxide emission and other gases derived mainly from the use of fossil fuels is a real problem. Air transportation strongly contributes for the global heating. Gas emissions by aircrafts correspond to 3.5% of the global emissions of greenhouse gases, and this level is expected to double in the next 15 years (11).

When we utilize the air transportation, we are responsible for a considerable amount of greenhouse gas emissions. The amount of CO_2 emissions per single passenger, in a flight from Frankfut to São Paulo (calculated with the Atmosfair Emissions Calculator (12)), is 3,55ton CO_2, which can be trated at 95.67 Euros at the carbon-trading market (*PointCarbon* (13), 24 Apr 2006). Table 2 shows the impressive amounts of per passenger/flight CO_2 emissions for flights from various airports to São Paulo.

Table 2: CO_2 emissions and equivalent carbon-trading market price of single-passenger travel to São Paulo, BRA (GRU)

From - City (Airport)	tCO_2	€
Bangkok, THA (BKK)	8,42	226,92
New Dehli, IND (DEL)	8,27	222,88
Hong Kong, CHN (HKG)	7,82	210,75
Singapore, SGP (SIN)	7,37	198,62
Shangai, CHN (SHA)	7,37	198,62
Stockolm, PNG (SMP)	7,31	197,00
Beijing, CHN (PEK)	7,23	194,85
Tokyo, JPN (NRT)	6,76	182,18
Sydney, AUS (SYD)	4,85	130,71
Seattle, USA (SEA)	3,95	106,45
Tel Aviv, ISR (TLV)	3,85	103,76
Oslo, NOR (TRF)	3,83	103,22
San Francisco, USA (SFO)	3,78	101,87
Copenhagen, DNK (CPH)	3,78	101,87
Budapest, HUN (BUD)	3,72	100,25
Cairo, EGY (CAI)	3,70	99,72
Vienna, AUT (VIE)	3,67	98,91
Prague, CZE (PRG)	3,67	98,91
Athenas, GRC (ATH)	3,63	97,83
Los Angels, USA (LAX)	3,59	96,75
Frankfurt, DEU (FRA)	3,55	95,67
Amsterdam, DEU (AMS)	3,54	95,40
Brussels, BEL (BRU)	3,50	94,33
Zurich, DEU (ZHR)	3,48	93,79
London, GBR (LHR)	3,43	92,44
Rome, ITA (FCO)	3,42	92,17
Paris, FRA (ORY)	3,40	91,63
Phonix, USA (PHX)	3,39	91,36
Denver, USA (DEN)	3,35	90,28
Minneapolis, USA (MSP)	3,24	87,32
Chicago, USA (ORD)	3,04	81,93
Madrid, ESP (MAD)	3,03	81,66
Detroit, USA (DET)	2,97	80,04
Dallas, USA (DFW)	2,97	80,04
Toronto, CSN (YBZ)	2,95	79,50
México, MEX (NLD)	2,90	78,16
Harare, ZWE (HRE)	2,89	77,89
Washington, USA (WSG)	2,70	72,77
Houston, USA (IAH)	2,70	72,77
New York, USA (EWR)	2,63	70,88
Philadelphia, USA (PHL)	2,62	70,61
Atlanta, USA (ATL)	2,57	69,26
Joahnnesburg, ZAF (JNB)	2,54	68,45
Miami, USA (MIA)	2,24	60,37
Santiago, CHL (SCL)	0,58	15,63
Buenos Aires, ARG (EZE)	0,37	9,97
Florianópolis, BRA (FLN)	0,09	2,43
Rio de Janeiro, BRA (SDU)	0,07	1,89

Sources: Atmosfair and PointCarbon (24 Apr 2006)

Projects that reduce such emissions stimulate of the carbon market. Countries included in the Annex I can use the Certificate of Emissions Reduction (CERs) resultant of the activities of the projects to fulfill their commitments established under the Kyoto Protocol (14).

RESULTS AND DISCUSSION

Passengers

The case-study to determine the potential of photovoltaic generation at airport buildings was made to the 66 public Brazilian airports. Initially the data from the energetic consumption and the amount of passengers was obtained from INFRAERO – Empresa Brasileira de Infra-Estrutura Aeroportuária. Table 3 shows the top 15 Brazilian airports in passenger numbers in 2005.

Table 3: Top 15 Brazilian airports in passenger numbers in year 2005.

	Airports	Passengers
1	São Paulo International Airport - Congonhas-SP	17.147.628
2	Guarulhos International Airport - SP	15.827.708
3	Brasília International Airport -DF	9.481.983
4	Rio de Janeiro International Airport - Galeão -RJ	8.657.139
5	Salvador International Airport - BA	4.554.096
6	Guararapes International Airport - Recife-PE	3.604.652
7	Santos Dumont Airport - RJ	3.562.297
8	Salgado Filho International Airport - Porto Alegre-PA	3.521.204
9	Afonso Pena International Airport - Curitiba-PR	3.392.986
10	Tancredo Neves International Airport - Confins-MG	2.892.393
11	Pinto Martins International Airport - FZ	2.774.240
12	Florianópolis International Airport -SC	1.548.833
13	Belém International Airport - PA	1.523.714
14	Vitória Airport - ES	1.517.578
15	Eduardo Gomes International Airport - AM	1.508.022

Source: INFRAERO

Irradiation

From the geographic location of the airports (latitude and longitude) it is possible to obtain information about the amount of global horizontal irradiation incident on the region, necessary for calculating the photovoltaic system power that will be able to supply the consumption of electric energy of the respective airports.

The global horizontal irradiation data were supplied by the SWERA project, and the calculation of the intensity of solar irradiation incident on the surface of the photovoltaic modules with surface tilt corresponding to the local latitude was obtained by the RADIASOL software*.

Table 4 shows the 15 Brazilian airports with the largest amount of solar irradiation. This calculation is initial and conservative.

Table 4: Top 15 Brazilian airports in amount of irradiation.

	Airports	Irradiation (kWh/m²)
1	Goiânia Airport - GO	5,813
2	Montes Claros Airport - MG	5,806
3	Teresina Airport - PI	5,767
4	Uberlândia Airport - MG	5,745
5	Uberaba Airport - MG	5,745
6	Campo Grande International Airport - MS	5,718
7	Parnaíba Airport - PI	5,706
8	Tancredo Neves International Airport - Confins-MG	5,697
9	Brasília International Airport - DF	5,696
10	Juazeiro do Norte Airport - CE	5,692
11	Pinto Martins International Airport - FZ	5,671
12	Petrolina Airport - PE	5,657
13	Belo Horizonte International Airport – Pampulha-MG	5,651
14	Carlos Prates Airport - MG	5,651
15	Viracopos International Airport - Campinas-SP	5,645

Source: SWERA and RADIASOL*

PV Power

With solar irradiation data, it is possible to calculate de PV power required to supply the electric energy consumption, as shown by the equation:

$$Pcc = \left[C / \left(I \times 365 \right) \right] / F \quad \textbf{(1)}$$

Where, Pcc = installed power (kWp); C = consumption (kWh/year); I = irradiation (kWh /m² /day); F= losses' coefficient in the transformation and conduction of power (20% power losses, due to the inverter's losses and associated electronic losses in terminals).

The consumption fraction used for the calculation of the PV power was to supply the total supply of electric energy of each airport complex. Table 5 shows the top 15 Brazilian airports in amount of annual consumption and the equivalent amount of required PV power.

Table 5: Top 15 Brazilian airports in amount of consumption and the equivalent amount of required PV power.

	Airport	Consumption (kWh/year)	PV Power (MWp)
1	Rio de Janeiro International Airport -Galeão-RJ	115.290.733	76,94
2	Guarulhos International Airport - SP	79.012.445	50,80
3	Guararapes International Airport -Recife-PE	20.417.812	13,32
4	Salvador International Airport - BA	17.497.566	10,91
5	São Paulo International Airport - Congonhas-SP	17.271.210	11,92
6	Eduardo gomes International Airport - AM	16.128.574	10,72
7	Salgado Filho International Airport - Porto Alegre-PA	15.957.099	11,04
8	Brasília International Airport -DF	13.287.084	7,99
9	Viracopos International Airport - Campinas-SP	11.643.490	7,06
10	Pinto Martins International Airport - FZ	10.207.454	6,16
11	Belém International Airport - PA	8.994.705	5,62
12	Tancredo Neves-Confins International Airport -MG	7.469.246	4,49
13	Afonso Pena International Airport -Curitiba-PR	7.170.515	5,08
14	Augusto Severo International Airport - Natal - RN	6.346.622	3,96
15	Santos Dumont Airport - RJ	5.391.973	3,60

Source: INFRAERO and Authors

When we analyze the amount of Brazilian passenger who used air travel in 2005 (Table 3) and the correspondent energetic consumption of the airport complex (Table 5), it is possible to determine the energetic density of the airports.
For the São Paulo International Airport, for example, the energetic density was 1kWh per passenger.
The total consumption of the 66 public Brazilian airports in 2004 was 401 GWh; to supply energy for this consumption, it would be necessary to install 261MWp in photovoltaic systems.
This amount would be enough to attract investors in the photovoltaic market to install PV production plants in Brazil; since the Brazilian energetic matrix is predominantly hydroelectricity, it would make the photovoltaic solar technology even cleaner.

Cost and finance of the photovoltaic systems
According to the polluter-pays principle (Principle 16 of the Declaration of Environmental and Development (15)), a preliminary study was made adopting a surcharge on the passengers' departure tax as an alternative to finance the installing of photovoltaic systems in Brazilian airports (16).

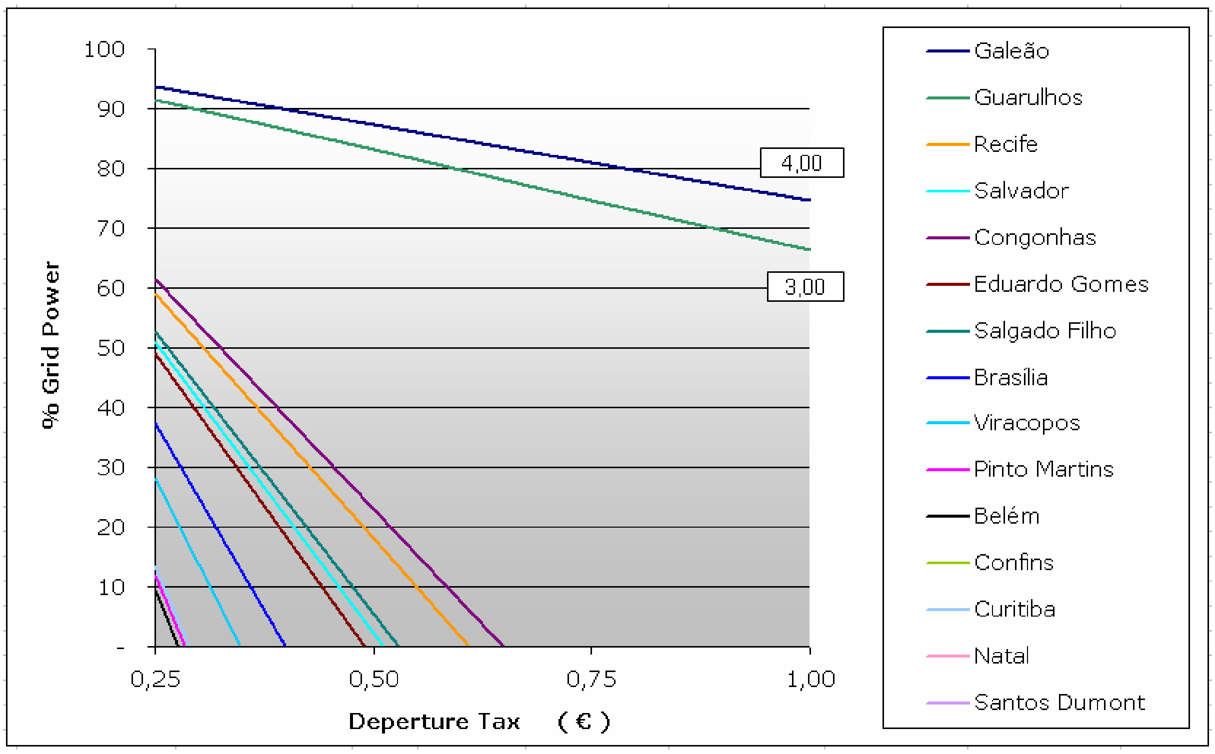

Figure 6: Reduction on the percentage of energy supplied by the utility with the increase in departure tax.

In the study, we concentrated on the 15 largest electricity consuming Brazilian airports (show on Table 5), and utilized local irradiation data for the correspondent airport. It was also adopted that the market price for the installation of photovoltaic systems would be 6 Euros per Wp.
Figure 6, was made considering that, the 96 million passengers that use air travel in Brazil in 2005 would be charged with a little raise of the 25 Euro-cents on the departure tax and then,

with the collected funds, finance installation of PV at selected airports according to a installation priority criteria.

The results show that, if the levy paid by the 96 million passengers were 75 Euro-cents, it would be possible to supply 100% of the energetic consumption of the of the Congonhas-SP airport in less than a year, installing 11,92MWpof PV. This analysis is valid for other Brazilian airports due to the fact that they have a lower consumption when compared with Congonhas-SP, with the exception of the Galeão and Guarulhos airports (respectively 4 and 3 Euros raise on departure tax necessary to make each of them 100% solar).
In Figure 6 it is also possible to observe the Curitiba airport, located at one of the Brazilian cities with the lowest intensity of solar irradiation among the 66 Brazilian airports, in which it would be possible to install the system and make it self-sufficient in energy with a raise of 35 Euro-cents.
This initial approach is conservative and will be further refined, as annual passenger numbers growth for the next ten years is expected to be in the range from 5 to 10% per year, and the associated compound increase in surcharge collection, is expected to be larger than airport annual energy demand growth. The increasing annual airport electricity savings in utility bills with the gradual increase of PV penetration every year have not been accounted for in the present analysis either. PV systems prices are also expected to decline with larger volumes, bringing further benefits to the economics of this approach.

CONCLUSIONS

Using solar energy in airports in substitution to other polluting power sources would make possible the emission of the CERs, which could be negotiated in the international market in the form of credit stocks which will be greatly valued in the next decade.
Issues and measures related to the impact of GHG emissions caused by aviation were left out of the Kyoto Protocol discussions so far, and air travel will not be penalized by CO_2 emissions until at least 2012. The aviation industry has therefore a unique window of opportunity to step forward and voluntarily propose compensation measures for the emissions related to its business. One such measure is the proposed project, which has the potential to not only make each and every airport worldwide a solar airport which generates its own electricity from a clean and renewable source, and also to promote the widespread use of this friendly generation technology with a very small financial contribution from patrons, who are in fact responsible for the emissions. Photovoltaic still lacks the scale to realize its cost-reduction potential, and the widespread acknowledgement of its benefits to become a mainstream technology. The solar airports concept can instantly double the current photovoltaic world market, with clear benefits to all the sectors involved in this truly win-win situation.

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** Computer software developed by the Laboratório de Energia Solar da Universidade Federal do Rio Grande do Sul – Brazil, which calculates the intensity of solar radiation on tilted surfaces facing any orientation through routines which determine the tilting effect on the receptor surface, azimuth deviate and the anisotropy of the solar radiation distribution in its direct and diffuse components*