PROJECT FINAL REPORT
PUBLISHABLE SUMMARY

Grant Agreement number: 232062

Project acronym: PV-SERVITOR

Project title: Autonomous cleaning robot for large scale photovoltaic power plants in Europe resulting in 5% cost reduction of electricity

Funding Scheme: Research for the benefit of SMEs

Date of latest version of Annex I against which the assessment will be made: 25th June 2009

Period covered: from M1 to M24 (01st September 2009 to 31st August 2011)

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1. Final publishable summary report

Executive Summary

The **PV-Servitor** project focused on concepts for a **fully autonomous** cleaning **robot** for **ground mounted large scale photovoltaic power plants**. The **PV-Servitor** is able to automatically clean glass surfaces of solar modules arranged in long rows in an unrestricted way. Its application will **increase the electricity output** of the PV plant at a lower service cost, thus **resulting in a user-benefit** by cost reduction of the electricity yield. The **quantification** of the user-benefit requires **specialised research and measurement capabilities** for each **individual plant**.

Europe's largest PV companies active in the **main European PV markets** such as **Germany and Spain** strongly supported this SME project as end-users and **granted access** to their large scale PV power plants in Germany and Spain. This end-user involvement will also help to secure the SMEs a **market success** after the completion of the PV-servitor project.

Tasks for research were lightweight construction, automated cleaning of glass surfaces, the synchronisation of technical and economic lifecycles, sustainable outdoor mobility including the challenge to replace rechargeable batteries with a long life energy supply system, unrestricted navigation and cognitive vision systems for pollution detection and cell inspection.

PV-Servitor was a research project **supported by the European Commission** (FP7 SME). The proposal was submitted on April 11th 2008 and the project started the **1st of September 2009** with a duration of **24 months**. Further information can be found in several languages such as Chinese, English, German and Spanish, at the project website: **www.pv-servitor.eu**

Summary description of project context and objectives

According to an EU publication photovoltaic (PV) is the **most capital-intensive** renewable source of electricity. Currently, the **generation costs** of grid-connected PV electricity in Europe range from € 0.25 /kWh to € 0.65 /kWh, depending on both local solar irradiation and market conditions. The average market price of electricity at the European Energy Exchange in the first quarter 2008 was € 56.20 /MWh, which is € 0.056 /kWh and more or less a still valid price as per today (19th September 2011).

The PV-Servitor project focused on the **reduction of the generation cost** of grid-connected PV electricity in Europe by 5% through **automated add-on services**. The automated service of a PV power plant was planned to result in an **increase of energy output of 8 %** and at a **cost 3 %** of the installation value of the PV power plant, resulting in a **benefit of 5 %** for the PV power plant operating company.

The **potential users** are all free terrain **PV-project operating companies** in **Germany** and other countries such as **Spain** and **Italy** with an EEG type income from photovoltaic energy production for the public-grid. The **EEG** is a very successful **German law** which states the **obligation of the grid-operator** to pay for renewable energy being fed into the public-grid.

Description of the main Science & Technology results / foregrounds

The project achieved **five patent applications** to the European Patent Office. After positive feedback for the first patent applications which was submitted ahead of the others **internationalisation** of the first patent application commenced to China, India, Israel, Korea and the United States.

However the **key question** of how to replace rechargeable batteries with a **long life energy supply system** remains to be solved in the future.

Potential impact and main dissemination activities and exploitation of results

The SMEs originally planned **direct utilisation** of the knowledge after the research project through a **product PV-Servitor**. However the research prototypes would require a development phase before they reach an industrial prototype status. Therefore the time to market is still some years ahead. After a training session on the 25th and 26th of January 2011 at EPO (European Patent Office) organised by the **European Patent Academy** about “Patents in Business” MS changed the plan for the use of foreground to include **licensing**.

The potential impact depends on the **benefit of cleaning**.

The ideal production of a 100% clean plant would be 100 %.

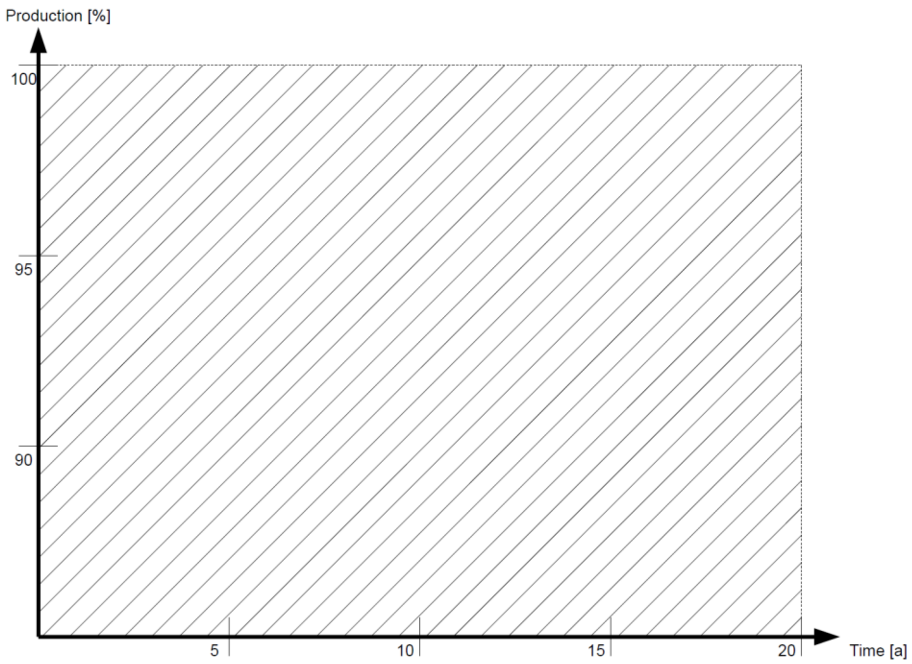

Figure 1: Benefit-analysis geometry - 100 % clean

Most end-users do not clean. Assuming an annual decrease of 2.5% per year, and a bottom line of maximum 10% the real production for dirty plants can be shown in a figure:

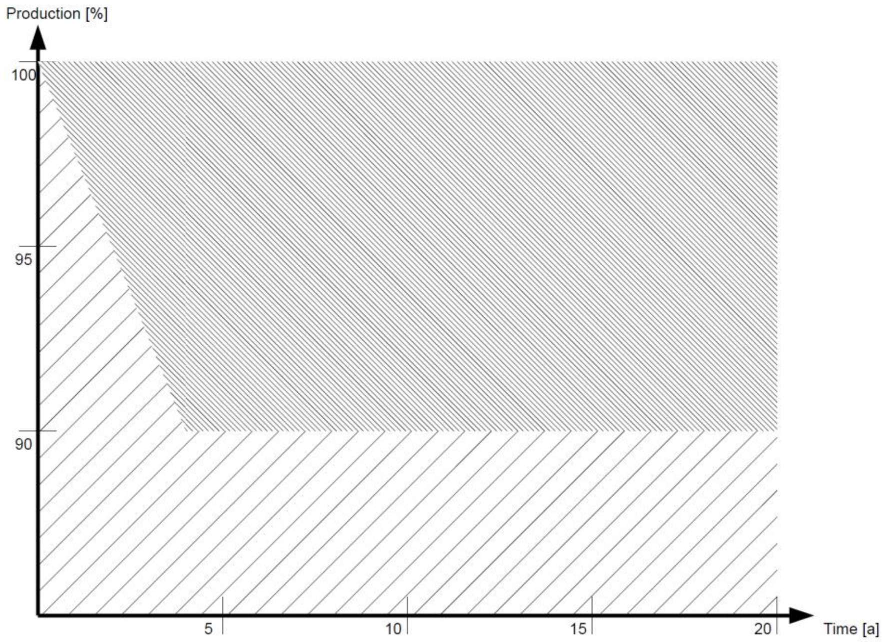

Figure 2: Benefit-analysis geometry - dirty

Assuming a cleaning interval of 6 months, the benefit analysis geometry shows, that only the blue part is lost due to pollution.

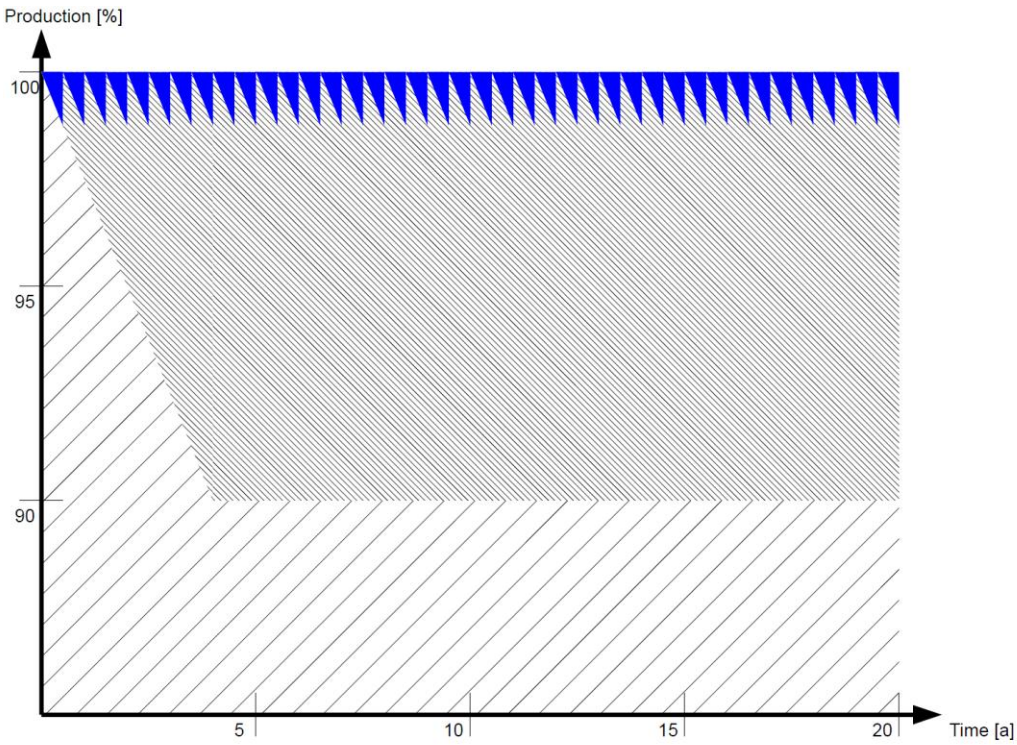

Figure 3: Benefit-analysis geometry - cleaned every 6 months

For calculations we use the final yield, pollution losses, cleaning benefit and time:

Y_M Maximum Yield per year = 100 %
Y_F Final Yield per year = 100% or below
G Final Yield per 20 years (viewed geometrically)
L Pollution Losses
B Cleaning Benefit
t time

For a **100 % clean plant** $Y_F = Y_M$. We therefore see:

$$G_{100\%\,clean\,plant} = 20a \cdot Y_M = 20a \cdot 100\% = 2000\%a$$

A **dirty** (never cleaned) **plant** has $Y_F < Y_M$:

t[a]	0	1	2	3	4	5
Y_F/Y_M	100 %	97.5 %	95 %	92.5 %	90 %	90 %

$$G_{dirty\,plant} = \frac{1}{2}4a \cdot 10\% + 20a \cdot 90\% = 1820\%a$$

$$L_{dirty\,plant\,20\,years} = \frac{1}{2}4a \cdot 10\% + 16a \cdot 10\% = 180\%a$$

$$L_{dirty\,plant\,per\,year} = \frac{L}{20a} = 9\%$$

Based on the assumptions (10% power increase after 4 years by cleaning, linear loss over 4 years and maximum base line of loss 10%), geometry shows that a **dirty plant**, that was never cleaned, **will lose 9 % per year of the possible energy over 20 years**.

A **cleaned plant** with a cleaning interval of 6 months still has $Y_F < Y_M$, however loses per year are quite small in comparison:

$$G_{cleaned\,plant} = 40 \cdot \frac{1}{2}0.5a \cdot 1.25\% + 20a \cdot 98.75\% = 1987.5\%a$$

$$L_{cleaned\,plant\,20\,years} = 40 \cdot \frac{1}{2}0.5a \cdot 1.25\% = 12.5\%a$$

$$L_{cleaned\,plant\,per\,year} = \frac{L}{20a} = 0.625\%$$

Therefore the **benefit of cleaning** is:

$$B = L_{dirty\ plant\ per\ year} - L_{cleaned\ plant\ per\ year} = 8.375\%$$

The **percentage based on energy production** calculates the end-user benefit much more specific than the commercial value of a **percentage based on the installation cost** as used in the initial simplified user benefit calculation as presented in the DoW [1].

However in reality it is hard to find plants within Europe that are as interestingly polluted as the scientifically monitored **PV plant Tiergarten** in Burgdorf, Switzerland.

Array		Measuring Conditions G [W/m²]	T_{Mod} [°C]	$U_{OC\text{-}STC}$ [V]	$I_{SC\text{-}STC}$ [A]	$P_{MPP\text{-}STC}$ [W]	Cleaning effect ΔP in %	Measurement Time	Date
3E8A	before	894	49.4	63.54	11.79	**518.5**		13:50:00	11.04.2011
	after	1002	38.1	63.48	12.94	**555.4**	**7.12**	13:26:24	13.04.2011
3E8B	before	941	50.8	63.44	11.61	**515.7**		13:54:00	11.04.2011
	after	1083	39.1	63.74	13	**560.2**	**8.63**	14:02:00	13.04.2011
3E8C	before	943	50.5	63.25	11.82	**511.6**		13:59:00	11.04.2011
	after	1102	38.2	63.36	13.07	**547.4**	**7.00**	14:11:00	13.04.2011
3E8D	before	887	51.1	62.84	11.71	**501.8**		14:02:00	11.04.2011
	after	1106	36.7	62.82	13.11	**540.2**	**7.65**	14:31:00	13.04.2001

Figure 4: Measured results of cleaning tests with improved prototype B in April 2011

For the final test the **most polluted free-field installation under service contract of the end-users** was searched **anywhere within Europe**. The PV power plant **Extremadura I** in **Castuera, SPAIN** was selected. At first glance a power loss of around 6 to 8 % of the nominal installed power was expected due to the **visual impression of pollution**. An astonishing result was the fact that at this PV power plant Castuera **cleaning** of PV modules with clearly visible pollution **only increased their power in the order of about 3 %**.

	Inverter	Cleaning Efficiency Gain
Cleaning Test 41	6.02	3.6%
Cleaning Test 42	6.03	4.1%
Cleaning Test 43	6.04	3.5%
Cleaning Test 44	6.05	5.1%
Cleaning Test 53	6.06	3.2%
Cleaning Test 45	6.14	3.9%
Cleaning Test 49	5.08	4.4%
Cleaning Test 50	5.09	2.8%
Cleaning Test 51	5.10	2.9%
Cleaning Test 52	5.11	0.9%
Mean Value Efficiency Gain		**3.4%**
Variation (maximum – minimum value)		4.2%
Maximum deviation referred to mean value		2.5%
Standard deviation		1.1%

Figure 5: Results of cleaning efficiency gain with prototype C in wet mode

Substantial user benefit might therefore be rather **limited to arid areas** found **outside of Europe**. The problem of pollution **depends significantly on the location** and further research on this topic is needed.

[1] PV-Servitor: Part B of Annex I to FP7 Grant Agreement (Description of Work), 25th June 2009, page 10.

Address of the project public website and relevant contact details

The SMEs created and updated the project specific website early in the project, well ahead of the plan in the DoW [2]. In a team effort Robotnik supported the translation into Spanish and Shadow checked the MS translation into English.

The main domain is:

http://www.pv-servitor.eu/

Three language specific subdomains are:

German
http://de.pv-servitor.eu/

English
http://en.pv-servitor.eu/

Spanish
http://es.pv-servitor.eu/

The language selection reflects the **native languages** spoken by the SMEs MS [3], Robotnik [4] and Shadow [5].

Following the internationalisation of dissemination two more language specific subdomains were created in an update of the project specific website:

Chinese
http://cn.pv-servitor.eu/

Hebrew
http://il.pv-servitor.eu/

The used subdomain name follows the Country code top-level domain [6] for the countries China (.cn) [7] and Israel (.il) [8].

The **translation to Chinese** was organised by MS at the end of the project. A final check and minor correction was **completed** with the **help of Shadow** and their **Chinese distributor** shortly after project end. However the **translation to Hebrew** remained a task for the **future**.

Relevant contact details are:

[2] PV-Servitor: Part B of Annex I to FP7 Grant Agreement (Description of Work), 25th June 2009, page 33.
[3] http://de.manu-systems.com/Hauptseite.shtml
[4] http://www.robotnik.es/es/
[5] http://www.shadowrobot.com/
[6] http://en.wikipedia.org/wiki/Country_code_top-level_domain
[7] http://de.wikipedia.org/wiki/China
[8] http://en.wikipedia.org/wiki/Israel

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Project logo

In a workshop after the annual review meeting with end-users, SMEs and RTDs selected the new project logo after viewing **7 competing drafts**. The winning logo is:

Figure 6: PV-Servitor project logo alternative A

A second valid form is:

Figure 7: PV-Servitor project logo alternative B

These logos also exist in black and white.

A mini style guide was made.

Figure 8: PV-Servitor project logo mini-style-guide

List of Beneficiaries

Beneficiary Number	Beneficiary name	Beneficiary short name	Country
1 (SME, Coordinator)	Manu Systems AG	MS	Germany
2 (SME)	Robotnik Automation S.S.L.	Robotnik	Spain
3 (SME)	The Shadow Robot Company Ltd.	Shadow	Great Britain
4 (RTD)	TEKNOLOGISK INSTITUT	DTI	Denmark
5 (RTD)	Hochschule Regensburg	MRU	Germany
6 (RTD)	Profactor GmbH	Profactor	Austria
7 (RTD)	Berner Fachhochschule	BFH	Switzerland
8 (end-user)	IBC Solar AG	IBC	Germany
9 (end-user)	Conergy Services GmbH	Conergy	Germany
10 (end-user)	SOLON SE	SOLON	Germany
11 (end-user)	ILIOTEC Solar GmbH	ILIOTEC	Germany
12 (end-user)	juwi solar GmbH	juwi	Germany
13 (end-user)	Solarparc AG	Solarparc	Germany

Table 1: List of Beneficiaries

Logos of all beneficiaries

Figure 9: Logos of all beneficiaries

List of Sponsors

ILIOTEC provides solar modules for research purposes and covers travel costs.

juwi provides solar modules for research purposes.

[Schöner Medien]

Schöner Medien sponsors rights of use at the project logo in the value of 10,608 €.

SOLON provides solar modules for research purposes.

Sunarc provides solarglas for research purposes.

BSW sponsors tickets for Intersolar 2011.

For cleaning experiments end of August 2011 in SPAIN especially for the evaluation of manual cleaning equipment and the comparison of the effect of manual and robot cleaning on the increase of power output, MS purchased several UNGER systems for manual cleaning of PV modules. UNGER kindly provided several additional samples of equipment free of charge. UNGER therefore qualifies as a sponsor for the project.