PROJECT FINAL REPORT

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1 Final publishable summary report

1.1 Executive summary

With 17 partners from 6 countries and coordinated by imec, the goal of the project was to develop new designs, materials, and manufacturing technologies for organic photovoltaics (OPV). One of the project's most visible highlights was the 12% world record for a cell developed by project partner Heliatek. The partners see a road to PV production with a cost that could eventually reach 0.5€/Wp, for modules that have a lifetime up and above 20 years and an energy payback time of less than one year. As important applications, they see building integrated PV, vehicle integrated PV, and fast deployable structures (greenhouses, shelters ...), which profit most from the unique selling points of OPV.

The project and its objectives

During 3 years, the X10D project pooled the knowledge and expertise of Europe's leading research institutes and companies involved with organic photovoltaics.

The objective of X10D was to eventually develop efficient, low-cost, stable tandem organic solar cells. And a second objective was to integrate cells into OPV modules that can compete with other technologies. All this by looking for and applying new designs, materials and manufacturing technologies. Because of this ambition, it was important to have project partners on board that could cover each segment of the value chain, e.g. material and device development and upscaling, large-area deposition equipment and processes, novel transparent conductors, laser scribing equipment and processes, and encapsulation technologies.

OPV solar cells are processed from either organic small molecules or organic polymers that act like amorphous semiconductors. The manufacturing processes are scalable, comparable to industrial printing. The X10D project was the first of its kind to consider and develop both major processing technologies: solution-processed polymers as well as vacuum deposition of small molecule-based OPV. Imec, as the only research institute and partner actively working on both processing tracks, took the role as project coordinator.

Typically, an organic solar cell absorbs only a small portion of the solar spectrum while the rest passes through unused. Tandem cells overcome this inefficiency. They layer OPV cells with different materials that each absorb light in another part of the spectrum, leading to a better overall efficiency.

OPV is part of the emerging domain of organic large area electronics, a palette of interrelated technologies that also result in organic LEDs, organic displays, and printable circuits. This makes the sector attractive for the material suppliers that invest in looking for and producing new molecules with the desired specifications.

Looking for new light-absorbing materials and designs

One of the project's goals was to design, synthesize and test new light-absorbing donor and acceptor materials, materials for which the production could be upscaled for use in the industrial-scale production of solar cells.

In close collaboration, the project partners have been able to develop new highly efficient small molecule and polymer donor materials. With the small molecules, they reached over 6% efficiencies in single junction solar cells, and with the polymers they measured more than 7%. This has resulted in

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multi-junction cells approaching 10%. In addition, it was proven that there is a practical way to synthesize these molecules on a large scale.

The project also prepared acceptor components with improved efficiencies. These compounds ideally show self-organization capabilities for improving charge transport capabilities through the organized layer, and they are thermally and chemically stable to enable sublimation deposition onto substrates. The project showed efficiency improvements of up to 8.4% in sublimated planar heterojunction cells.

While experimenting and refining new materials, the X10D partners also worked on better fabrication processes, e.g. developing several approaches for loss-free charge conversion interlayers and middle electrodes for solution-based devices, one of the key challenges for making tandem devices from a solution. A successful combination turned out to be ZnO (zinc oxide) nanoparticles deposited with a polymer mixture (PEDOT:PSS).

With the new materials and fabrication processes, tandem cells were made that stand out as the highlights of the project: record multi-junction devices with efficiencies of 8.9% and 9.6%, and a world-record tandem cell with a 12% power conversion efficiency cell on 1 cm^2, which was externally certified.

The next step was to upscale these results to large-area cells, and eventually to integration in modules. Also in this area the project partners made considerable progress. Several options for large-area coating were studied, e.g. in a patterned (inkjet printing) and full-area (sot die coating) fashion, and even the option of spray coating was investigated.

Several large-area cells and modules were realized. At the 2014 European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC 2014), e.g., imec showcased a fullerene-free OPV module of 160cm2 with a conversion efficiency above 5 percent, and a semi-transparent OPV module with an efficiency above 4.5 percent. The fullerene-free module was created by thermally evaporating small molecules in different active layers, with a process that been shown to improve the device stability. The semi-transparent modules used a system of metal oxide layers and thin metal films as transparent electrical contacts, effectively combining double glass window properties with device encapsulation, pointing forward to window-integrated photovoltaic solutions.

Improving and assessing the lifetime of OPV cells and modules

One of the challenges in bringing OPV cells to the market has always been their sensitivity to degradation and the need for a near-perfect encapsulation. So this also had to be an important area of attention for X10D.

First, the partners studied the intrinsic degradation mechanisms of materials and cells. They then used the results of this analysis to select the most stable device architectures and the best materials for the photo-active layers, transport, electrode and contact layers. Cells made with various processing techniques were then compared for stability, identifying the most critical factors.

This work also allowed making recommendations for the most appropriate lifetime testing conditions. Lifetime measurements on devices and modules based on benchmark materials and architectures have to be carried out in an inter-laboratory study with standardized test protocols. This study, including outdoor lifetime testing and testing under accelerated conditions, is still ongoing.

As for the encapsulation, the X10D partners developed a low-cost polymer, flexible encapsulation system with high H_2O-barrier properties. They also showed that this encapsulation technology results in a lower environmental impact than existing techniques. The next step is now to transfer this

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technology to a roll-to-roll pilot line, and to test and characterize adhesive materials to prevent lateral permeation coming from the edge of the cells.

Unique selling points & road ahead

OPV has a number of unique characteristics over conventional solar technologies. OPV cells and modules can be made into almost limitless forms and shapes, with coloring and transparency. They harvest energy under more diverse light conditions then silicon cells. They can be produced efficiently, through highly automated low-cost low-energy roll-to-roll printing. And last, they have excellent sustainability characteristics, with a short energy pay-back time and low carbon footprint. X10D used these unique selling points to investigate and identify potential markets.

At the current stage of R&D, there is still a wide gap between the power conversion efficiencies of record lab cells (i.e. 10-12%) and modules (i.e. 6%) processed with scalable production technologies. The important challenge in the coming years will be to minimize this gap by successfully demonstrating the scalability of laboratory concepts, developing new photoactive materials and upscaling their synthesis. According to the present insights, the efficiency of a scaled OPV module (either via printing or evaporation) is expected to gradually increase and cross the barrier of 10% somewhere between 2016 and 2020. In parallel, the lifetime of cells is expected to increase, while the production cost will gradually decrease, with high-volume production starting after 2016.

The project's impact

In total 49 peer-reviewed publications in conferences/journals were published in the course of the project and some more are still in the pipeline. The world record certified 12% cell efficiency by Heliatek and the paper from TU/e presenting efficient triple-junction polymer solar cells published in JACS 2013 both secured press and public attention.

Four patents based on the foreground of X10D have been filed, on a variety of items: fullerene-free OPV stack, multilayer encapsulation, production-ready additives and embedded patterned metal structures. Other patents may follow, such as new oliogomer absorbers and synthesis method of metallic nanoparticles.

It is clear that this project has helped to deliver genuine world class technology and competitiveness for Europe in this field. In conjunction with the academic/industrial collaborations that have been formed as part of this project this therefore places Europe in a very advantageous position to try to commercially exploit this area of technology. The partners imec, Holst Centre, ECN, and TU Eindhoven have since bundled their expertise in Solliance, a transnational research alliance for research and development in the field of thin-film photovoltaics in the ELAT-region (Eindhoven-Leuven-Aachen triangle). Heliatek has recently obtained about 7% efficiency of tandems in roll-to-roll manufacturing and they are looking to start EU manufacturing of OPV on flexible cells which could create significant jobs and revenue. There are also several other industrial partners, particularly of equipment and components, who stand to gain directly and more imminently from this work, like 3DMM, SPG and Agfa as all have products close to market and some with potential applications beyond OPV.

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1.2 Project Context and Objectives

OPV is considered as an important emerging PV technology with the prospect of achieving very low costs. The potential for cost reduction is based on the compatibility with high throughput processing (a factor of at least 10 higher than for other technologies) on light weight flexible substrates with less demanding and complex manufacturing equipment. Additional features which make OPV very attractive compared to other thin film PV technologies are:

- easy integration in a wide variety of devices by a large freedom of design
- tunability of the colors by molecular engineering of the organic materials
- semi-transparency
- excellent sustainability profile with potential for short energy pay back times

All of these features are important add-ons to the functionality of PV systems which could lead to a wider applicability of OPV in various market segments that are inaccessible to conventional inorganic PV technologies.

Looking back at the start of the project, the situation was as such that, in order to enable OPV to enter competitive thin-film PV markets, **breakthroughs needed to be realized** to improve its competitiveness in terms of *efficiency, durability, production costs and market acceptance*.

1) **Materials synthesis, processability and scalable synthesis routes for novel absorber materials.**
   At that time, state of the art organic photovoltaic cells showed a lack of light absorption in a broad range of the solar spectrum considerably limiting the overall power conversion efficiency (PCE). New absorber materials had to be synthesized in order to enhance the light harvesting in a broader range of the spectrum compared with existing hero absorbers, such that a combination of absorbers in tandem devices successfully harvests the incident light between 350 and at least 850 nm.

   These materials also need to guarantee long-term stability in the device and have to allow processing in production conditions, such as high rate deposition or solubility in eco-friendly solvents. Sustainability has to be foreseen also in the aspect of scalable synthesis.

2) **Development of monolithic 2- and 3-terminal multijunction cells to maximize PCE**
   In order to achieve modules with PCEs above 10%, PCEs above 12 % at the cell level are required. This is due to geometrical constraints that lead to a loss of photoactive area and reduce PCE when small area devices are scaled to larger areas. Efficiencies above 12% are not expected from single cells mainly due to (a) the relatively narrow absorption spectra of organic materials that limit the photogenerated current, and (b) when one increases the harvesting wavelength to increase current, the photogenerated voltage is inherently reduced. Therefore, efficiencies larger than 12% can only realistically be reached by multijunction concepts. In a multijunction cell, individual sub cells made of different absorbers are physically placed on top of each other. Depending on the design (2- or 3-terminal) either the photocurrent or the photovoltage can be enhanced.

3) **Scaling of processes from cell to module**
   The scaling from small area single cells to complete modules where different cells are monolithically connected onto the same substrate is probably the most critical step to ensure competitiveness

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against competing technologies. The module design along with enabling thin film deposition techniques allow for both at once maximizing PCE and minimizing fabrication costs.

The module design has to optimize the balance between minimal electrical losses and maximal area coverage, which is strongly governed by the current and voltage generation in the constituent cells in relation to the sheet resistance of the electrodes and interconnection schemes.

Deposition technologies that can provide uniform, multilayered film deposition at high speed are required.

Alongside, high speed patterning at high resolution has to be implemented; which can be done by direct printing or by post-patterning by e.g. laser scribing.

To increase process yield and quality, in-line process control and device performance testing at all crucial stages will be of high value.

4) **Increase cell and module lifetime to allow broad market entry**
Reported lifetimes of current devices limit the range of market application to specific niche markets where durability is not an issue. Even though there have been an increasing number of publications in recent years on degradation issues of OPV, a more detailed study is necessary in order to derive a better understanding of the intrinsic degradation mechanisms of OPV devices. Additionally, good control over external influences has to be ensured by high-quality, low-cost encapsulation. Finally, extrapolation protocols based on accelerated and field testing have to be identified to guarantee accurate lifetime predictions.

5) **Enhance industrial uptake.**
To allow easy uptake by industry of this emerging thin-film technology, many hurdles need to be mitigated:

    a) Material up scaling and ink formulations have to be possible in an eco-efficient way

    b) Efficiency and lifetime performance have to be benchmarked against standardized (IEC) testing protocols

    c) Cost issues in different processing technologies have to be determined to allow identification of target applications for market entry and successful acceptance. An option to enter rapidly in niche markets is the development of low investment, low cost-of-ownership technologies with high design flexibility, like inkjet printing or spray coating. Other technologies might have to be developed for higher-end, large volume applications in building integrated PV and outdoor, grid-connected power generation markets.

    d) Life cycle assessment is crucial in order to identify the most sensitive components increasing the price and ecological footprint and how to avoid them.

    e) Communication with the industry is essential to enhance exploitation of an emerging technology like OPV

The **Main Objective** of X10D is to develop efficient, low-cost, stable tandem organic solar cells by applying new designs, materials and manufacturing technologies to create market-competitive OPV modules. This can be quantified more explicitly as:

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- To increase the current PCE to achieve at least a 12% on cell level (1cm²), and 9% on module level (100 cm²)
- To guarantee a minimum of 20 years life for OPV modules on glass, and 10 years on foil
- To decrease the cost under 0.70 €/Watt-peak

Achieving these objectives will create a large **market potential for OPV**, which will be described in a **White Paper**.

This main objective is itemized into different specific objectives to guarantee a successful control of the existing risk in achieving the final goal. In order to achieve such challenging objectives X10D will simultaneously work on: Materials, Efficiency, Lifetime, and Steps towards market entry and acceptance, including process development, scale-up and its related dissemination and exploitation. The first three are essentially **scientific objectives** while the latter one can be regarded as a **technological objective**:

1) **Materials**

   Advances in the efficiency of organic solar cells rely on the development of improved materials, in particular the light absorbing, electron donor component of the active layer. But, the synthesis has to be carried out carefully to ensure our **material objectives**:

   a) Absorbers that **allow external quantum efficiency >80%,** characterized by strong absorption and good charge transport

   b) **Complementary absorbing materials** which allow maximised cell voltages and matched currents in tandem cells, optimised for the custom processes of the consortium and available in **appropriate quantities**

   c) The feasibility of **large scale** synthesis with **sustainable** chemistry in all synthetic routes has to be proven

2) **Efficiency**

   As described above, it is essential to develop **novel high-efficiency device architectures**, since it has been debated in literature[1] that single junction cells have limitations that prohibit efficiencies beyond 10%. X10D will realize structures that allow higher efficiency by building **2- and 3-terminal multijunction devices**. The consortium will also study techniques that allow **enhanced light-incoupling** in combination with these novel architectures. This will result in hero cells with **power conversion efficiency of 12% on 1 cm² area cells.** It is envisaged that this will require absorber materials that can result in power conversion efficiency up to 8% in single junction cells.

   When devices are connected to form modules, less total area is active due to interconnection requirements, hence the difference between cell and module efficiency. X10D will dedicate efforts to module design in order to maximize the **active area coverage to levels above 85%.**

Table 1: Summary of efficiency objectives of X10D (1000 W/m², AM1.5)

[1] G. Dennler, Advanced Materials, 2009, 21, 1323–1338

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	Cell (at least 1 cm²)	Module (at least 10 x 10 cm²)	
		Active Area	Total Area
Glass	12%	9%	7.5%
Foil	8%	6%	5%
Foil with alternative to ITO	7%	5%	4.5%

The table above summarizes the X10D efficiency objectives as a function of the type of substrates and device. Foil is preferred over glass for some market applications, however it also establishes requirements and limitations –mainly processing temperature related- that lead to lower efficiencies. Since X10D will also develop the processing of low-cost alternatives to ITO as transparent conductors on foil, efficiency objectives are also specified for such substrates.

Additionally, **pre-normative testing protocols** for efficiency measurements of multijunction modules, which will have their specificities over single junction cells and modules, will be developed, described and made available to the public and industry.

3) Lifetime

The lifetime requirement is derived from the typical usability lifetime of electronic goods that could potentially be powered by solar cells. Targeting different applications will demand very different lifetimes. While for low-cost devices, a lifetime of 3-5 years (operational lifetime of 3000-5000 hours) is regarded as the market-entry point, from 20 to 25 years is necessary for either grid or off-grid electricity generation applications.

X10D will undertake the study and characterization of the **intrinsic degradation mechanisms**. We will establish a series of experimental procedures to systematically study the impact on lifetime of each module component. The synthesis routes of the new absorber materials, explained in more detail in the description of the first workpackage, will strongly focus on creating shifts in the molecular energy levels which will thereby also contribute to more stable compounds. The feedback obtained from the results and modeling will be iteratively used to improve the lifetime of subsequently fabricated photovoltaic devices.

In parallel, **pre-normative testing protocols** for lifetime, accelerated lifetime and weathering measurements will be developed to allow us to develop **extrapolation protocols** based on intrinsic degradation mechanisms and to determine acceleration factors for encapsulated devices.

Finally appropriate packaging in order to minimise the H2O and O2 penetration rate to the device will be investigated to preserve the intrinsic stability of the developed device concepts.

This will lead to:

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d) Definition of **extrapolation protocols** to guarantee over 20y lifetime of OPV devices, made available to the public and industry

e) Demonstrate, based on the extrapolation protocol, **20 y lifetime for glass-glass** encapsulated devices

f) Demonstrate, based on the extrapolation protocol, **10 y lifetime for foil-foil** encapsulated devices

4) Steps towards market entry and acceptance

Communication with industry is essential to enhance exploitation of an emerging technology like OPV. Besides a broad industrial partnership in the X10D consortium, strong dissemination of the results and progress in X10D will be carried out. One of the means for this is to organize a workshop for industrial stakeholders in OPV in the course of the project.

A benchmark against standardized (IEC) testing protocols will be done to guarantee broad industrial acceptance of the results from the pre-normative efficiency measurement and lifetime extrapolation protocols developed within X10D.

A large effort in this project will be dedicated to process development and related scale-up. For the different processing technologies cost, energy and life cycle assessments will be done to identify the most sensitive components of the OPV device and process and to describe how to minimize them to realize an overall cost <0.7 €/Wp for production of OPV modules. This analysis will be used to benchmark OPV to other thin-film PV technologies and to do a market analysis. This has to lead to identification of first applications to enter the market, accompanied by a description of the production process. An OPV roadmap will describe also future markets and how to enter those.

These outcomes will be described in a **White Paper on status and market potential of OPV.**

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1.3 Main S&T results/foregrounds

1.3.1 Highlight from WP1

WP1.1: Development of Optimised Light Absorbing Donor Polymers

The development of wide band gap materials in WP1 afforded the polymer **SiIDT-BT**, with a band gap of 1.8 eV, an absorption maximum around 630 nm, a HOMO energy level of -5.4 eV and a LUMO energy level of -3.6 eV. With PC[70]BM as the acceptor material and a co-solvent additive in a conventional device configuration, **SiIDT-BT** afforded a maximum power conversion efficiency of 7.0% resulting from a J_{sc} value of 12.7 mA/cm^2, a V_{oc} of 0.89 V and a fill factor of 0.62.

Two polymers with relatively narrow band gaps that both afforded power conversion efficiencies above 8% in single junction cells have been prepared in WP1 (Figure 1). **DPPTT-T(C-3)** is a DPP-based polymer with an absorption maximum around 800 nm, a HOMO energy level of -5.1 eV and a LUMO energy level of -3.7 eV. Utilising PC[70]BM as the acceptor material in an inverted device configuration, **DPPTT-T(C-3)** afforded a maximum power conversion efficiency of 8.5% resulting from a J_{sc} value of 21.5 mA/cm^2, a V_{oc} of 0.58 V and a fill factor of 0.68. **BBTI-1** is a newly developed benzotrithiophene-based polymer with good solubility in chlorinated solvents as well as in environmentally friendlier non-chlorinated solvents such as tetrahydrofuran, toluene and xylene. **BBTI-1** has an absorption maximum around 720 nm, a HOMO energy level of -5.2 eV and a LUMO energy level of -3.7 eV. Again, using PC[70]BM as the acceptor material in an inverted device configuration, **BBTI-1** afforded a maximum

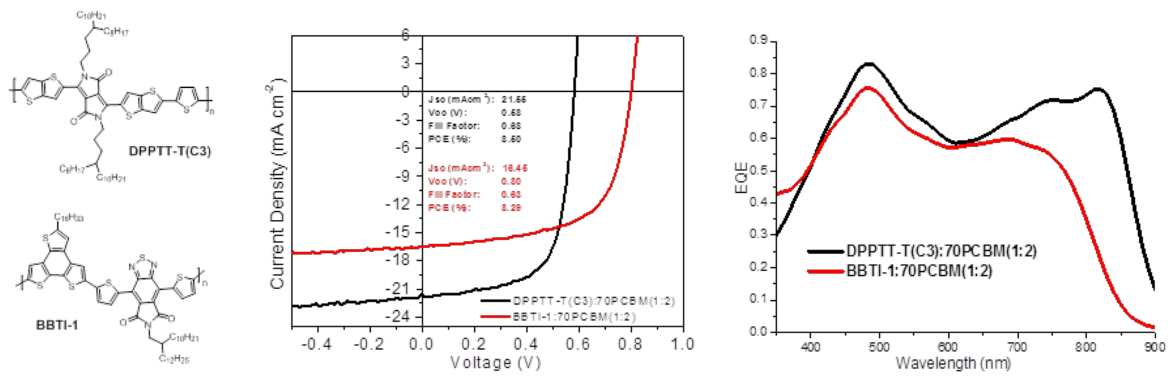

Figure 1: Chemical structures (left), JV curves (middle) and EQE responses (right) for best performing DPPTT-T(C3) and BBTI-1 devices.

power conversion efficiency of 8.3% resulting from a J_{sc} value of 16.5 mA/cm^2, a V_{oc} of 0.80 V and a fill factor of 0.63.

Additionally, DPP-based polymers with very narrow band gaps (1.3 – 1.1 eV) have been prepared, which give rise to unprecedented high quantum efficiencies beyond 900 nm and power conversion efficiencies reaching 5% despite the expectedly low V_{oc} values due to the narrow band gaps.

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WP1.2: Development of Optimised Light Absorbing Small Molecules

For the development of optimised light absorbing small molecule donors, Heliatek demonstrated that by adding a small amount of a proprietary processing additive EA002 to the bulk hetero junction, a device consisting of proprietary small molecule donor HDR055 mixed with C_{60} achieved an outstanding performance with a PCE of 7.6% in a single junction device (V_{oc} = 0.93 V, j_{sc} = 13.1 mA/cm^2 and FF = 62.7%, at absorber layer thickness of 30 nm). The processing additive thereby has no electrical function, but it optimizes the molecular nanomorphology.

Activities have also focused on the development of optimised light absorbing small molecule acceptors. In particular, an optimization of several aspects of planar heterojunction solar cells based on boron subnaphthalocyanine chloride as a donor material has been carried out. The use of hexachlorinated boron subphthalocyanine chloride as an alternative acceptor to C_{60} allows for the simultaneous increase of the short-circuit current, fill factor, and open-circuit voltage compared to cells with fullerene acceptors. This is due to the complementary absorption of Cl_6SubPc versus SubNc, reduced recombination at the heterointerface, and improved energetic alignment. Furthermore, insertion of a thin diindeno[1,2,3-cd:1′,2′,3′-lm]perylene layer at the anode results in a very significant 60% increase in photocurrent owing to reduced exciton quenching at the anode. The simultaneous improvement of all three solar cell parameters results in a power conversion efficiency of 6.4% for a non-fullerene planar heterojunction cell.

WP1.3: Screening of Active Materials

A material screening protocol was developed in order to establish the methodology that must be followed to screen adequate absorbers with the potential to be integrated into photovoltaic devices with PCE>12%. The methodology was initially applied to commercially available materials in order to maximize the power conversion efficiency and validate the protocol. Subsequently, the material screening protocol was used in the assessment of small test-scale batches of photoactive active materials as well as for the evaluation of scaled-up batches of promising photoactive materials.

WP1.4 Sustainable Upscaling of Active Materials

We have clearly proven the practical feasibility of large scale synthesis of photoactive materials by synthesising more than 25 g of one of the promising DPP-based donor polymers. This successful scale-up has moreover enabled the detailed study into commercially viable, non-halogenated solvents for active layer processing, which has resulted in achieving comparable solar cell device performance using non-halogenated solvents such as xylenes and mesitylenes.

1.3.2 Highlight from WP2

WP2.1: Charge conversion inter-layers and middle electrode for tandem cells

Both for the polymer tandem cells and for vacuum processed oligomer OPV the project partners found suitable materials to be used in charge conversion interlayers: For vacuum processing, **IMEC** developed heterojunctions of Ytterbium doped bathocuproine doped (BCP:Yb) and molybdenum tri-oxide (MoO3), This combination can now be used as standard charge conversion layer. For polymer tandems, ZnO proved to be the most reliable n-type charge conversion material that can be used e.g. with

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PEDOT:PSS for wet processing tandem cells. For polymers, the combination of PEDOT: PSS/ZnO turned out to be the most reliable solution.

WP2.2: Monolithic 2- and 3-terminal solution processed tandem cells

The race for efficiency in the field of polymer solar cells gave hero devices with tandem cell layout having up to 8.9 % efficiency. These devices combined PCDTBT:[70]PCBM as blue/green absorber with PMDPP3T:[69]PCBM as red/IR absorber. In a triple device stack, even **9.64% power conversion efficiency** were reached by **TU/e**.

Ikerlan together with **TNO** made an in-depth comparison of the pro's and con's of monolithic 2- and 3-terminal tandem cells. As a result, 2-terminal devices turned out to be favorable in most parameters.

WP2.3: Monolithic 2- and 3-terminal vacuum evaporated tandem cells

Monolithically connected two-terminal devices were developed, which reach 12% PCE, as it was defined as final project target for X10D. Similar to the polymer devices, also the vacuum processed devices were most efficient with triple cell layout. The **12% efficiency OPV Heliatek device** combined a green absorber (UDR023) and two red absorbers (HDR014) in a triple absorber stack. 12% are so far the best ever reported OPV efficiency worldwide!

Further, two new concepts were found that have the potential to boost OPV efficiency: **IMEC** invented the so-called "energy cascading solar cell", which is fullerene free, and gave 8.4% PCE – which is record for fullerene free OPV. As another concept, **Heliatek** found a way to use processing additives also in vacuum processed OPV. These additives enhance the fill factor of OPVs by further improving the nanophase separation of the donor and acceptor in the bulk heterojunction.

WP2.4: Micro-optics: Light incoupling schemes and optical modeling

Focus within WP2.4 was on the simulation of high-efficiency OPVs. **Heliatek** made predictions how to make 13% PCE solar cells, using a new absorber material from WP1 in a triple cell stack. Unfortunately, so far this material was available in mg amounts only. These findings have been made at the very end of the project. As an outlook, further work will be done after the end of X10D to exploit this result.

WP2.5: In-depth characterisation of tandem cells

Two **round robin** studies organized by **ECN** have been carried out among five of the partners to enhance the understanding of deviations in device characterization. A detailed assessment of the differences in measurements due to intrinsic, theoretical and practical issues of the characterization of organic based tandem cells and possible improvements thereof has been described in Deliverable 2.4.

1.3.3 Highlight from WP3

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WP3.1: Large area alternative transparent conductors to ITO

In this task, we have been working on the development of an transparent electrode based on silver grid lines overcoated with highly conductive PEDOT. The idea was to reach <5% area coverage with a sheet resistance of <1 Ω/□ and use processing technologies that are compatible with roll-to-roll processing.

At **TNO**, a methodology was developed to embed high topology, screen printed silver lines in a resist where the lines are now part of the substrate and show no topology on the top side. With a thickness of 120 µm and a pitch of 2.5 mm, the area coverage is below 5%. The thickness of 6 µm ensures sheet resistances lower than 1 Ω/□. In collaboration with **Agfa** and **SPG Prints**, a suitable PEDOT formulation was formulated to ensure a decent wetting on the resist and the silver for slot die coating and inkjet printing purpose.

These electrodes were evaluated as transparent bottom electrode in organic solar cells by **TNO**, **ZAE**, **Solar Press** and **Heliatek**. Also the patterning by laser of the electrode was investigated by **TNO** and **3DMM** with the idea of creating a master electrode foil that could be reshaped according to the desired design. Although the experiments at **Heliatek** were successful, these activities aroused several issues of the technology like amongst others non-homogeneous wetting, trench formation at the edge of the silver, sensitivity to the quality of the resist, unsufficient scribing due to variations in line width and thickness.

After several attempts of different versions of embedded grid samples at the partners, it was decided to fall back to additive inkjet printed silver lines on foil. Hereby the sheet resistance increases to 5-7 Ω/□ which is still much better than ITO on foil. This is proven by an improved fill factor in evaporated solar cells at **Heliatek** and efficiencies of 5% on small modules. The larger modules are still under development. Lessons learnt from the PEDOT reformulation result in suitable alternative transparent electrodes. The roll-to-roll compatibility has been confirmed by the design for a roll-to-roll inkjet print tool by **SPG Prints**.

WP3.2: Deposition techniques for up-scaling uniform films to large area

This task addresses the multilayer coating on large area (10x10 cm^2) with area coverage of 85%. Several technologies have been evaluated to achieve the most suited production technology for multi-junction cells. Halfway the project, the number of technologies were narrowed down to slot die coating for homogeneous large area deposition which should be combined with laser patterning on the one hand and inkjet printing for direct patterning. To strengthen the activities to successfully scale up the fabrication of solar cells, two additional partners focused their work on large scale processing. **ECN** attempted to bridge the gap between work package 2 and 3 by starting to inkjet print tandem solar cells. **3DMM** extended their activities from R2R laser patterning to develop complete on a roll-to-roll line combining slot die coating with laser scribing.

The successive coating and drying of wet layers was successful achieved for both technologies on small scale sheet-to-sheet as well as on roll-to-roll. The fabrication of single junction cells and modules was realized with materials from inside and outside the project (3.5% and 4.2% for cells respectively and 3% for modules).

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For tandem solar cells, inkjet printing in a tile-wise interconnection brings about issues with wetting behavior on different surfaces. Also the PEDOT formulation applied shows holes which generate shorts in the tandem cells. Slot die coating of tandem cells introduced inhomogeneous layers on the available equipment. Therefore tandem cells were manufactured successfully at **ZAE** by doctor blading which is considered as precursor to slot die coating because of the similar technology. Doctor blading is however limited to 5 cm width because of the blade, but in combination with laser patterning an area coverage of over 85% was easily reached.

At **Heliatek**, high deposition rates for relevant production conditions were investigated. Due to a slower progress in other work packages, the tests were performed with projects from outside the project. Deposition speeds of 4 Å/s, which is much faster than lab tests, were realized with similar performance as at low speed.

WP3.3: Design and construction of modules with optimal area coverage

This task consists of several smaller tasks to obtain modules with optimal area coverage. Halfway the project, the question was raised about the need for effort on 3-terminal devices. After an collaborative effort between several partners of different work packages, it was decided to omit all work on 3-terminal solar cells because of the inferior properties for several parameters compared to 2-terminal cells.

In the beginning of the project a model was developed at **ECN** to quantify the optimal cell dimensions in relation to the resistances occurring in the electrodes. This has been put into practice for determining the ideal cell width for ITO based as well as alternative transparent electrode based under different light intensities.

A second aspect is the obtaining a high geometrical fill factor to lose the lowest active area possible in a module. The interconnection is feasible by laser patterning or by tile-wise coating of the layers. **Solar Press** succeeded in lowering the dead area of tile coating to 1.5 mm to achieve a geometrical fill factor of 66%. Laser processing on the other hand allows for much smaller dead areas of around 250 µm resulting in geometrical fill factors above 90%. Finding the ideal laser processing parameters demands for low wall and debris formation of the scribed layers. This has been successfully realized by several partners on single junction, large area modules. The feasibility of tandem cells has been convincingly proven by **ZAE** in another EU project (RotRot) on similar materials that these settings could be copied for the X10D materials as well.

3DMM has shown that the production of organic solar modules on a roll-to-roll coating/drying system with laser patterning is very well feasible with meters of coated modules as result.

WP3.4: In-line cell/module performance testing at 5 m/min

A final important aspect for the upscalability of organic solar modules on a roll-to-roll system is the possibility to test the modules inline at speeds >5 m/min. **Solar Press** has struggled with the complete development of a tool due to an unfortunate funding situation. However, several individual steps towards an integrated system has been performed and are ready to be implemented. The lighting system, the electronics and the mechanical concept and design have been evaluated and the best options are chosen.

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1.3.4 Highlight from WP4

WP4.1 Identify intrinsic degradation mechanism

Initial studies highlighted the critical importance to investigate the air and light stability of evaporated devices, while most materials, devices are proven heat stable. Air sensitivity of the devices can be mitigated by adapted packaging, hence improvement of intrinsic light stability was selected as the focus of the work in the project.

Numerous light and heat stability evaluation of transport layers (TL) in single junction prototypical ZnPc:C60 devices have been conducted. These studies served as input for the selection of the most stable TLs for the design of next generation tandem cells in WP2. Hole TLs that were evaluated in the frame of the project are MoO3, MeoTPD, MeoTPD:MoO3, BF-DPB: MoO3, BF-DPB:NDP-9, BF-DPB:C60F36 and BF-DPB:C60F48, while electron TLs : BCP:Yb, BCP:Ca, NBphen, TmPyPB. As a conclusion BF-DPB:C60F48 and TmPyPB are selected as hole and electron TLs, respectively, resulting in over 1000 h stability at 85°C in dark and T80 of 800 h under continuous illumination in ZnPc:C60 single junction devices.

We also investigated the light stability of two complementary photoactive bulk heterojunctions, DTDCTB:C60 and TPTPA:C70 in single junction and finally their combination in an inverted tandem cells with MoO3 and BCP:Yb as recombination layer. The device stack and layer thicknesses were optimized in WP2 to reach over 8% initial performance. The stability of these devices reached T80 of 2000 h under continuous solar illumination at room temperature.

We investigated the long term stability (>14000h) of encapsulated and inverted organic solar cells stored in dark at different controlled temperatures and moisture settings. To characterize the degradation kinetics, we investigated the acceleration factors using the Arrhenius model and showed that the diffusion of moisture through the cell's packaging is mainly responsible for the loss in PCE.

Using different lock in Imaging techniques such as electroluminescence lock in (ELLI), dark lock in thermography (DLIT), and illuminated lock in thermography (ILIT) it was possible to visualize the moisture's diffusion through the cell's encapsulation in time.

WP4.2 Development of barrier foil by wet process

A disruptive barrier foil manufacturing has been developed in the X10D project. It is based on the use of liquid materials (instead of plasma deposition processes) and low temperature conversion. An up-scalable roll to roll process has been developed and sample in the range of 10-3 g.m-2.d-1 (WVTR) has been manufactured of the basis of the roll to roll machinery. In addition, the lab processing has demonstrated the possible achievement of barrier foils in the range of 10-4 g.m-2.d-1.

The advantages of the x10d process developed by Arkema and CEA has been highlighted in the life cycle analysis. The potential low cost manufacturing of the gas barrier foils should be particularly important for the preservation of the cost of final OPV applications.

WP4.3 Characterization and ageing analysis of barrier materials and packaging

Three aspects related to the study of the whole packaging (flexible) have been investigated. It allowed a better understanding of the impacts of not well considered factor as the water/oxygen

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ingress coming from the edge of the device through the adhesive (CEA, Arkema) or the degassing of the conductive embedded substrates developed in the project (TNO).

For this purpose, innovative testing (on the basis of calcium degradation) using samples which mimic encapsulated OPV has been developed by CEA and TNO. Thanks to the accurate assessment of the gas barrier properties of encapsulating adhesives (used to laminate the gas barrier foils), new adhesives formulations have been developed jointly by Arkema and CEA.

In addition, ZAE performed ELLI, DLIT, and ILIT measurements in order to investigate locally the impact of water ingress from the edge on the active layer of inverted organic solar cells and highlighted the relevance of this issue for the achievement of reliable encapsulation and improved lifetime.

WP4.4 Lifetime measurements of devices and modules

Two round robins have been organized and the aging data of the two types or organic solar cells (wet processed polymer and vacuum small molecules) have been analyzed. The main stress factors depending on the aging conditions and the cell architecture have been identified. New aging conditions (higher temperature, UV) have been integrated in protocols thanks to the better and better stability of the organic devices. Critical factors as encapsulation and contacts are clearly identified. Lifetime in the range of 20 years are demonstrated.

1.3.5 Highlights from WP5: Costs, environmental impact and market analysis

WP5.1: Cost of Ownership calculations

From the cost of ownership calculations carried out by Holst Centre, it is concluded that future module manufacturing costs of OPV (both evaporated and solution processed) can potentially cross the barrier of € 0.50 per Watt peak by consecutive technological improvements to the current standard designs:

- Proceeding from a patterned deposition to full area deposition in combination with laser scribe patterning assists in decreasing the dead area.
- Replacing ITO for a metal grid with highly conductive PEDOT increases the active area.
- Omitting a barrier by replacing it with a non-transparent metal foil substrate reduces the cost further.
- Finally it was shown that replacing silver by copper electrodes would bring the cost down to a very competitive level.
- Increasing the efficiency of OPV by introducing multi junction device architectures

These various concepts have not all been reliably proven on lab scale or production level, but demonstrate the low cost potential of the technology.

Various cost calculations have been performed during the project by comparing solution processed vs evaporated organic PV modules, S2S vs. R2R processing as well as to show the influence of the barrier on the total costs of an Organic PV system. The overall conclusion is that the costs of OPV is strongly dominated by the materials and reveal further that the economy of scale with increased production and reduced material cost is absolutely necessary to realize the very low cost targets and make OPV a competitive PV technology in high volume markets.

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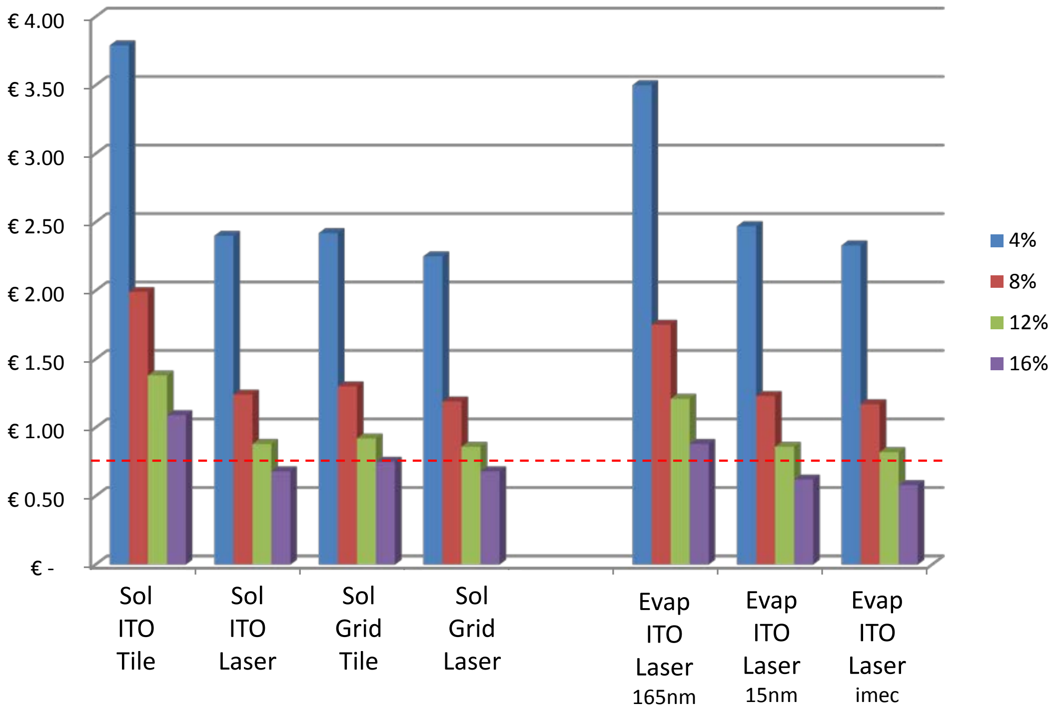

Figure 2: Cost calculations for varying power conversion efficiencies for solution processed and evaporated tandem solar modules

Although beyond the scope of the technical activities of X10D, additional calculations were carried out on the Balance of System (BoS) Cost structure of a BIPV application using OPV modules Here, it was concluded that relative BoS costs are lower, when compared to conventional rooftop c-Si modules. Cost reductions are mainly found in mechanical BoS (substructure, racking), although electrical BoS (inverters) may increase. With a proper system design, taking into account module oversizing and orientation dependence, the inverter costs, being the main cost driver, should be optimized.

WP5.2: Life Cycle Assessment

The following main conclusions from the LCA studies performed in X10D can be made:

OPV has a high potential for achieving advantageously low environmental footprints. This is first and foremost due to the exceptionally low energy and materials intensity for the deposition of its photoactive layers which represents an advantageous differentiating factor compared with other PV technologies: on the level of the energy payback time this potential is already realized. **Even with modest module efficiency of 4% energy payback times < 1 year** can be achieved. This is competitive with mature commercial glass based thin-film PV (e.g. a-Si, CIGS).

Achieving a good carbon footprint is more challenging, at least in devices containing ETFE in the front sheet of the encapsulation structure. This is because ETFE has a notoriously high embedded carbon value which was rationalized in terms of greenhouse gas emissions during its upstream synthesis chemistry in the present report. Alternative fluoropolymers have been proposed to lower the carbon footprint.

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Large sensitivity of environmental footprint to efficiency, lifetime & degradation: high module efficiency and lifetime as well as low annual performance degradation are essential boundary conditions for a small environmental footprint. As an example of this sensitivity the critical influence of these parameters on the carbon footprint was shown.

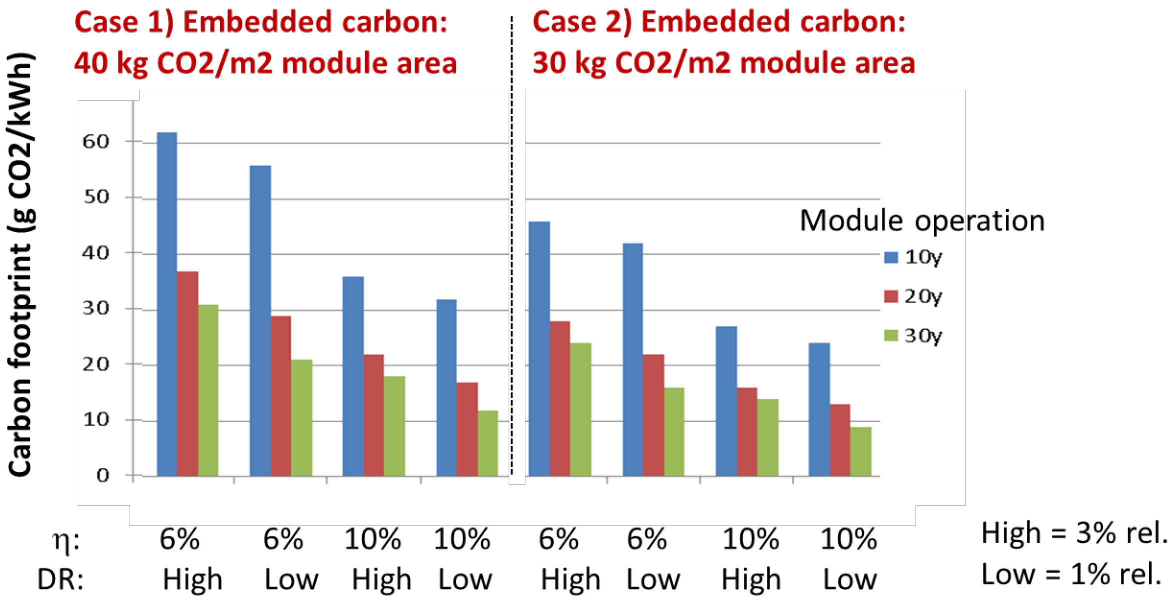

Figure 3: Influence of module efficiency, degradation rate and lifetime on the carbon footprint(for two different values of embedded carbon).

WP5.3: Market analysis and developments

A market analysis report is written based on information gathered from literature, external reports and X10D (industrial) partners. The market analysis report describes the current situation in the PV landscape and sketches the current technological status and future market potential of OPV for specific targeted applications like BIPV, automotive and various fast deployable applications. These targeted applications were selected after identifying unique selling points like flexibility, semi transparency, freedom of design, beauty to give OPV a competitive advantage over other flexible PV technologies.

Concerning the market chances for OPV, the technology should not be seen as a replacement for current PV technologies. Instead, OPV is a disruptive technology that opens access to completely new markets, where energy scavenging so far has not been exploited. This may have different reasons like e. g. aesthetic considerations, or more practical ones, as weight or form factor. OPV opens completely new design options, for example due to its ability to be adapted in colour, transparency or shape. As one of the first PV technologies, with OPV it is possible to produce large semi-transparent devices with full area coating. Structuring of these devices can be carried out either by additive technologies (as printing) or by subtractive ones (like laser ablation). Each of these approaches has its own upsides and creates chances in different applications. All these properties make OPV an interesting option for applications in the automotive sector, as well as in the building integration market. These markets are potentially enormous: World-wide, each year 20 million car roof windows are used. The use of facade glass is 20 million square meters annually, within the EU only. All these markets become accessible,

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once a certain threshold of device performance is reached. The project X10D has had this topic in focus: The efficiency of OPV cells could be increased to 12 % within X10D, which is the current world record for OPV devices. OPV lifetime has been studied in detail as well, and the durability of OPV devices could increase further, which is another prerequisite for a widespread application of OPV. In summary, OPV is a truly green technology, giving access to so far non-developed markets. To reach this goal, however, continued research and development will be required before a commercial breakthrough can be expected.

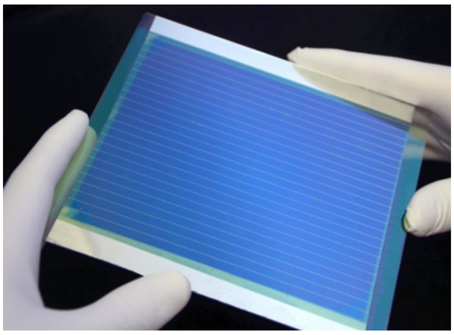

Figure 5: Novel fullerene-free OPV cell concept was used to process an OPV module with a conversion efficiency of 5,3% © Imec

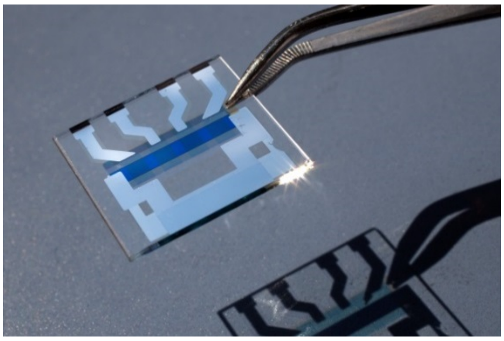

Figure 4: OPV solar cells from the R&D lab © Heliatek GmbH

1.3.6 Highlight from WP6

The target of the communication concept is to inform the commission and an interested public about the actions and progress of the integrated project X10D within the 7th framework program. Tangible results such as products, items, graphical representations and samples are rounded up by intangible results such as scientific papers. Tools to promote the results were workshops, conferences, a project website, posters, brochures, flyer, logos, partner websites, movies and promotional material.

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Figure 6: X10D promotional material: Brochure, Flyer, Pen, Roll-up

We created a comprehensive dedicated website for the project updated on a regular basis. On the website (http://www.x10d-project.eu) you find information about the Project and the areas: Overview, Partners, Links, News, Events and Jobs for an interested public. It contains an internal area, a big pool of important information for all partners, which they can call it up all the time. In the internal area are integrated some Workflows for a better interactive work with the partners and for a more coordinated collaboration.

Figure 7: Project Website public area

One highlight of the dissemination of results was the development of two project movies. The movies give the public a very good overview about the whole project, their included partners and how their interaction with each other was during the project.

The consortium committed to exploit the results, contribution to norms and standards, and new researches. We created a specific section in the internal area of the X10D webpage dedicated to innovation and technology transfer. Moreover there had been organized an OPV stakeholder meeting in Athens with the title “From Material to Market” to facilitate the uptake of project outcome by industry. The X10D partners also attended related industrial meetings to promote the technology transfer.

1.4 Impact

1.4.1 IMEC

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As a research center, imec continuously seeks opportunities to validate its technological know-how by engaging into partnerships with industrial players that focus on commercializing OPV products or related technologies.

The project brings an accurate view on the position of OPV within the general PV market and a clear roadmap on how this new technology can evolve within the thin-film PV area for the coming years to become a mature player in this market. Participation to this consortium enabled imec with:

- Access to new materials and characterization techniques
- New developments in device architectures and deposition technologies
- Deeper understanding in lifetime mechanisms of multijunctions and module, e.g. through round-robin

Novel fullerene-free OPV cell concept

The project allowed imec to develop a novel OPV device concept, the energy cascade architecture, resulting in high-efficient, fullerene-free cells. A high-impact journal publication combined with a press release raised a lot of attention to this concept, which is currently further explored on experimental level within imec, as well in discussion with interested other R&D partners to be further exploited.

Exploitation plans

Therefore, this X10D project enabled imec to strengthen its position as a dedicated OPV research center with strong knowledge on understanding and characterization of device architectures, deposition technologies, and lifetime mechanisms.

In this role, imec participates together with ECN, Holst and TU/e in the Solliance initiative (www.solliance.eu) with the aim to create a technology platform for the development of OPV from lab to fab and assist industries active in the OPV value chain (materials, equipment, integration) in their ambitions to accelerate the commercialization of their specific business. This will occur through a shared research programme.

Exploitation towards industry occurs via process and product transfer to companies; ECN together with Holst and imec use the acquired knowledge to collaborate within the frame of the Solliance shared research programme with companies like.

- ThyssenKrupp (BI(O)PV for industrial facades)
- SmitOvens, NL: efficient drying and curing of PEDOT and Ag
- VDL-Flow, NL: the realization of a R2R production line for efficient and high yield production of all solution processed OPV

The acquired competences and know how that have been obtained within X10D will also be exploited further towards R&D via running EC projects like ArtESun and MUJULIMA and future EC projects.

Dissemination activities

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Imec participated in several conferences or exhibitions to represent the X10D project, as well in oral presentations as with a booth, to distribute the dissemination material (pens, flyers, brochures) and show project poster and demo devices.

Several journal publication have resulted from the project, with the one on the novel fullerene-free energy cascade OPV concept generating highest impact.

Press releases have been made as well on the project initiation or progress, as on imec's results within the project.

1.4.2 CEA

Potential impact of the technology for OPV

CEA INES is implicated in the development of organic photovoltaic, from the optimization of elaboration processes on glass and flexible substrates to the study of the role of interfaces on ageing of PV cells and nano-structuration of active layer. Since 2006 encapsulation of OPV cells received a lot of attention. The X10D project has allowed us, in collaboration with Arkema, to develop a gas barrier technology that should eventually lead to gas barrier films with outstanding performance/cost ratios, improve OPV lifetime and preserve the cost advantage of OPV. In addition, the better understanding of the flexible encapsulation issues, with the development of specific testing and materials (adhesives), will be particularly useful to protect OPV devices studied in CEA. Finally the collaborative work related to OPV aging issues will be an important source of knowledge for the future development of reliable OPV in CEA.

Potential impact of the technology in other fields

From a wider point of view, the development of the gas barrier film technology and of the whole encapsulation process within X10D, should allow to tackle other markets outside OPV; it can be hoped that the organic electronic device market will become available for some of the most performant gas barrier films we are developing.

Dissemination activities

The X10D project has led to two scientific papers.

CEA has participated at the LOPEC exhibition (see section 2. A2)

A patent application has been filed as a result of the work done within the X10D project. This patent, which is co-owned by CEA, and Arkema has been published, since the embargo date has been reached. The reference of the published application is given in section 2.B1

Exploitation of results

The results obtained through this project towards the development of encapsulation solutions for OPV cells are promising. We believe that the objectives, in the form of deliverables, have been attained and will allow to OPV lifetime.

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1.4.3 ECN

Main dissemination activities

- Contribution as co-author to a few X10D publications
- LCA Contribution to white paper as composed by OEE (OE-A) (not published yet?)

Exploitation plans

ECN and Holst centre form an alliance with imec and TU/e called Solliance (www.solliance.eu) with the aim to create a technology platform for the development of OPV from lab to fab and assist industries active in the OPV value chain (materials, equipment, integration) in their ambitions to accelerate the commercialization of their specific business. This will occur through a shared research programme.

The acquired competences/know how that have been obtained within X10D are currently/will be exploited towards R&D via running EC projects like Clean4yield, MUJULIMA and future EC projects.

Exploitation towards industry occurs via process and product transfer to companies; ECN together with Holst and imec use the acquired knowledge to collaborate within the frame of the Solliance shared research programme with companies like.

- ThyssenKrupp (BI(O)PV for industrial facades)
- SmitOvens, NL: efficient drying and curing of PEDOT and Ag
- VDL-Flow, NL: the realization of a R2R production line for efficient and high yield production of all solution processed OPV

1.4.4 ZAE

High precision processing for flexible substrates and determination of degradation mechanisms in lifetime studies

Since the start of X10D, the ZAE Bayern investigated the use of R2R compatible printing and coating techniques and of efficient patterning processes for the manufacturing of organic solar cells and modules. Furthermore, we studied the influence of different environmental factors on the stability of solar cells and modules and gained more insight in the degradation mechanisms.

Now, the ZAE Bayern is one of the leading institutes in the research and manufacturing of upscaled modules with a high geometric fill factor. During the last two years, a lab-sized slot-die coater (50-100 mm wide head) and a roll-to-roll coater (loop-coater), operating on 100 mm web, has been set-up and produces efficient organic solar cells, comparable to other printing/ coating technologies. With the help of X10D, it was possible to focus on research studies regarding homogeneous coating and printing of single and tandem solar cells and to investigate the important parameters for reproducible manufacturing of efficient solar modules on the basis of typical semiconductor: fullerene materials. Using laser ablation as patterning technique improved the gained efficiency of the modules, increasing the geometrical fill factor to a very high value that has not been reached world-wide till now. Furthermore, now being able to manufacture reliable printed single solar cells, tandems and modules, we have been able to set up long-running degradation studies. We could investigate intrinsic factors for degradation on typical devices and specify degradation mechanisms for the semiconductor:

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fullerene material. We further determined and investigated environmental influences and degradation mechanisms of devices with the additional help of lock in imaging techniques for failure analysis. With all these efforts we have been able to do some ground-breaking work in the field of degradation. Especially, we were able to visualize the moisture's diffusion through the cell's encapsulation using electroluminescence lock in imaging, dark lock in thermography as well as illuminated lock in thermography.

The ZAE Bayern aims for further collaboration with the partners after all the successful work, especially in the field of module manufacturing and degradation studies. We look forward to further academic and industrial collaboration. In the future, we will continue to investigate organic solar cell modules and their use for further applications as for example the integration in buildings and for automotive.

In short, ZAE Bayern will exploit the research work from the X10D project in supporting and initiating new projects in this field, leading to further employment and supporting or even enhancing its role as one of the leading research institutes in the field of organic solar cell research.

1.4.5 Heliatek

The world's first tandem OPVs in production

By mid-2014, Heliatek is the largest OPV manufacturer worldwide. A first roll-to-roll production line, operating on 300 mm web, using vacuum deposition has been set-up and produces efficient organic solar cells. X10D delivered learnings for making such tandem and triple devices that now can be used in the production facilities. The volume production reaches meanwhile 7.0% power conversion efficiency for flexible, foil-encapsulated devices.

After a start with single cell layout, Heliatek's production relies on tandem OPVs, similar to the ones developed within the X10D project. Due to the lead time before introduction into a large volume product, X10D materials are not used in this line yet, however future cell stacks will use the knowledge created within X10D. Also further developments within Heliatek's chemistry department build on these results.

Heliatek aims for a large-volume production of OPVs. For this reason it currently seeks funding for a >1m web width roll-to-roll production line. Technological preparations for this line are ongoing with full force. In parallel, the Heliatek R+D team and its technology partners work heavily on the enhancement of OPV performance with respect to efficiency, lifetime, possible transparency and added values that make OPV a relevant technology for future energy harvesting. Heliatek's business development department develops new products with key customers for new markets, such as building integration and automotive.

In summary, Heliatek will exploit the project outcomes within its own first production line, as well as in the next one which is currently in the planning phase. This will create further employment within Europe, both in the OPV production itself, and in the supplier and customer industries.

1.4.6 IKERLAN

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IK4-IKERLAN is a non-profit private research institution whose mission is to generate new knowledge and transfer new technologies to the surrounding industry in order to improve their competitiveness. In this way, our exploitation of results focuses on using the new advances achieved within X10D to continue researching on the field and participating in new related projects, both international and national. Regarding socio-economic impact and societal implications, IK4-IKERLAN works along with its clients to survey the market and identify new applications for this technology. Given the business network in which we are immersed, some examples are optoelectronic devices for industrial sectors that include tool-machinery, capital goods as household appliances and autonomous wireless sensors and RFID tags for transport, healthcare and wellness.

1.4.7 Imperial College

Additive and Annealing Free Processing of Organic Solar Cells with Efficiencies Exceeding 8%

The two high-performing light-absorbing donor polymers developed at Imperial College which give rise to power conversion efficiencies above 8% in single junction photovoltaic devices can both be solution processed without any use of solvent additives or annealing steps. The aspect of simple processing conditions and thus a robust and reproducible protocol for device fabrication is an important consideration when designing and synthesizing novel photoactive materials and obviously of great interest and significance for the commercialization of organic solar cells. Additionally, to the best of our knowledge, the achieved power conversion efficiencies of 8.3% and 8.5% achieved by simple solution processing from a single solvent system is the best OPV device performances reported to date in a standard device configuration (conventional or inverted) without the use of any solvent additives or annealing steps. Additionally, both polymers have complementary absorption spectra which would allow simultaneous use in multijunction devices.

1.4.8 UAM

The field of molecular materials with technological applications, particularly the field of molecular photovoltaics based on phthalocyanines and subphthalocyanines, is a highly interdisciplinary area. This field, which encompasses synthetic organic chemistry, chemical physics, solid state chemistry and physics, among other disciplines, can be especially fruitful for the EU society since it focuses on applied research. In particular, the development of solar cells based on red-absorbing pigments (i.e. Pc and derivatives) strongly contributes towards improving the quality of life of the society. The molecules proposed and prepared in the framework of this project have shown the potential to outperform current state of the art organic dyes, providing a pathway towards commercially competitive organic solar cells.

The results that stem from our research in the framework of the project have been published in prominent scientific journals (i.e. 13 publications), and presented to other scientist in nearly 30 international conferences. Worth mentioning is the interview to Tomás Torres in a National TV/radio program directed to undergraduate students and the general public, where he explained major results and breakthroughs of our research. Also, .an article about the talk of Prof. Tomás Torres at Universidad

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Nacional Autónoma de México has been published in the journal "Gaceta Facultad de Química" edited by this university.

1.4.9 Technische Universiteit Eindhoven (TU/e)

The X10D project has been important for the Eindhoven University of Technology. Energy is one of the three strategic areas defined by the TUE in which it aspires to be one of the world's foremost research institutions in research, inspired by societal needs. The TUE aims to simultaneously push the frontiers of science, product development, and societal implementation of new technologies within a European context. As such it is extremely important for the TUE to participate in projects like the X10D in which the TUE can collaborate with leading industries, research institutes and academia in Europe. On a more local level the TUE is member of Solliance the alliance of TNO, TU/e, Holst Centre, ECN, imec, and Forschungszentrum Julich for research and development in the field of thin film photovoltaic solar energy in Eindhoven-Leuven-Aachen triangle region. Being a research oriented university, scientific results are primarily disseminated in peer-reviewed publications and conference contributions. In this respect the X10D project has been very successful and influential. Results from X10D have been published in leading scientific journals among which four publications in *The Journal of the American Chemical Society* and one paper in *Advanced Materials*. The paper on tandem and triple junction solar cells published in JACS in 2013 is attracting considerable attention as it has been cited more than 100 times within one and half year after publication. Results have been presented also at about a dozen of international conferences. Through the X10D project the TUE has been able to further strengthen its position in this research field, which has resulted in a number of successful and a number of pending project applications in the area of polymer solar cells with industry and research institutes.

1.4.10 TNO/Holst Centre

TNO/Holst Centre is part of the new Solliance OPV initiave, teaming up with ECN, imec and TUe. Solliance collaborates with industrial partners from the whole value chain from materials and equipment over production towards integration. Solliance differentiates from other OPV research institutes as VTT, CSEM, Fraunhofer ISE by operating in a shared research model to accomplish necessary development for and with industrial partners towards a successful commercialization of the partner's products.

Specifically in X10D will the developed knowledge on electrodes and large area processing be used to exploit and to strengthen TNO's position to transfer processes and products to related industrial partners. These achievements in X10D will speed up the commercialization of OPV on short term as the need for ITO replacement still is countlessly expressed by solution processed OPV manufacturers.

The results obtained in the X10D project are presented on several conferences in invited and oral talks in Europe and abroad. One article on the work has already been published and three more are in preparation to disseminate our achievements in the project.

The main reasons for TNO to participate in X10D are to build-up further expertise in the field of upscaling high efficient organic solar cells. By reusing technologies developed already for OLED at Holst Centre, the developed upscaled technologies can be exploited towards companies involved in OPV to

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assist them in accelerated commercialisation. By joining a European project such as X10D, TNO can strengthen and expand its OPV network by close collaboration with other universities, institutes and companies prominently active in the OPV field.

1.4.11 Solar Press

Solar Press aims to be a leading developer of lightweight, low cost, flexible solar panels based on organic photovoltaic (OPV) technology.

The consortium of the X10D project is ideally suited to provide the components required to accelerate the scale-up and commercialisation of OPV manufacturing.

The low cost of manufacturing of OPV modules using high-throughput printing and coating methods is a key advantage over existing PV technologies.

- The in-line OPV testing system developed by Solar Press has application in a wide range of organic and printed electronic applications, where rapid and automated characterization of the electrical properties of devices produced on a roll-to-roll (R2R) process is required. Application beyond OPV include OLEDs, OTFTs and organic photodetectors
- In-line testing of R2R produced OPV devices allows immediate electrical characterization of all devices as they are produced on a R2R production system. This allows poorly functioning devices to be identifed and issues with production processes to be detected quickly minimizing wastage of materials. This can potentially enable closed-loop optimization of device performance through feedback of measured properties to production parameters such as layer thickness. In-line testing can therefore support both OPV R&D and production. This technology has the potential to accelerate OPV development and reduce the cost of production.
- Solar Press completed concept design of the in line test system, and designed and built an efficient, compact and uniform LED light engine. A novel, low cost, high speed 4th quadrant IV scanning system was developed, alongside more conventional source-measure unit based systems was developed to perform the electrical measurements. A shuttle-based reciprocating contact probe system was invented and designed to enable electrical contact to be made with moving web based OPV devices.
- Unfortunately Solar Press suffered from financial issues in the final year of the project, and had to close down operations in London. This prevented the completion of the in line inspection system. However, the company has now reestablished itself in Swansea, Wales, as part of strategic partnership with the SPECIFIC Integrated Knowledge centre. The company is working to raise new funding to rebuild its operations, and is planning to complete inline test system, which will support future development of OPV modules for indoor energy harvesting and outdoor photovoltaic applications
- The project enabled SP to further develop the R2R slot-die deposition processes for the photoactive and charge transport layers of the OPV module. In addition the project supported development of R2R electrode deposition based on slot-die coating and gravure

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printing of specially formulated silver inks. This is an important step in enabling full in line OPV production and testing.

Solar Press has given invited presentations at a number of UK and European events that have included updates on its work on R2R process development for OPV. This includes:

- SID UK Printed Electronics, London, September 2013
- Welsh Centre for Printing and Coating In Line Metrology Workshop, September 2013
- ID TechEx Plastic Photovoltaics and Energy Harvesting, September 2013

1.4.12 SPGPrints

Introduction

SPGPrints is a market leader in rotary screen printing. Its screen printing technology is also used for industrial printing i.e. RFID tags and conductive tracks for solar cells. On the other hand SPGPrints has a strong base in inkjet printing. The X10D project has made it possible for SPGPrints to discuss the use of inkjet for this application with material developers and suppliers and module designers.

Developing the deposition process

SPGPrints aims to find a place in the value chain where it can add value to the consumable in this application: to make a good inkjet ink from these materials. During all the interaction that the X10D project provided, it was concluded that materials providers not always identify this type of role in the value chain. First aim is to realize the function of the module in the final application, be it conductivity, transparency, photo activity or something else. When these materials approach the phase of application in production, inevitably there needs to be sufficient attention to industrial module production processes.

Developing the roll-to-roll production system

SPGPrints has supported partners in the X10D project in chosing the right inkjet technology (notably the print head). These discussions have made clear that for functional materials printing, some requirements are different from the requirements in more traditional inkjet markets. Partly they might even be in contradiction. For instance normally quite some volume of ink will be recirculated to have a uniform temperature and sufficient degassing. However with expensive and experimental inks the volume should be small.

SPGPrints has found these insights very valuable. It has finally resulted in the decision to develop a new much more flexible platform for these applications. The design has not been finished at the time of ending of the X10D project. The intention from SPGPrints is to present this design to the market and potential customers in 2015. It is expected that the application of single pass inkjet as production tool in these markets will only take off after that. The market in the coming years will be merely research institutes and pilot process lines. SPGPrints believes that, although this seems to be a necessary entry into this world, the importance of the production owner must not be under-estimated.

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1.4.13 Solvay

Solvay is a multinational chemical company well positioned in the field of (inorganic) Photovoltaics. Solvay provides materials integrated in the front sheet, back sheet and also encapsulate. Solvay is very active in further expanding into new businesses, like in the field of organic electronics. This project has allowed to reinforce its expertise in synthesis of materials for OPV and it was a good format to gain further expertise in the field of OPV and especially identify the technical road to tandem success. Overall knowledge built on scale up of active compounds will be useful for further development in the field of organic electronics

1.4.14 VDI-VDE

The company's primary objective is to promote R&D in information technologies, to assist governments in developing initiatives to for accelerating technological development and to speed up product and process innovation in SMEs. Today, VDI/VDE-IT has a profound knowledge in coordinating European projects.

VDI/VDE-IT was responsible for administrative and technical support of management including back-office services, IT- based project management including internal and external communication, administration and reporting including internal monitoring and review of deliverables & milestones, documents as well as reports. We ensured a proper dissemination of results both within the consortium and to the general public as well as a proper communication between the consortium and industry to enhance exploitation. Furthermore we safeguarded a proper protection and exploitation of intellectual property developed within X10D. The X10D project made it possible to expand our knowledge in coordinating European projects and especially in the IT- based project management. We will also use the gained experience the new established contacts and relationships in order to enhance the position in the market.

1.4.15 Agfa

Agfa focused within the X10D project on developing silver and PEDOT based inks and formulations suitable for large area and low cost OPV electrodes. At the end of X10D, Agfa already offers to different customers worldwide some of the products developed within X10D. Depending on how fast the OPV market will grow in the upcoming years, Agfa will further support and adapt these products to meet customers needs. However, in mean time Agfa will also exploit the X10D findings outside OPVs applications by offering more or less adapted products to the general market of other low cost printed applications like RFID, OLEDs, membrane switches, etc. Therefore, Agfa will continue further development and scaling up based on the X10D project findings and is already actively cooperating with business and other customers to realize significant turnovers. This will enable further employment within Europe in R&D, production and business support of the involved products and additionally in the supplier and customer industries. A more detailed impact overview is given below.

1.4.16 3D-Micromac

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Within X10D 3D-Micromac focused on the development and improvement of laser processing technologies for printed electronics. This included developments for roll-to-roll laser processing of flexible substrates. Roll-to-roll manufacturing of organic solar cells is expected to drastically increase throughput compared to sheet-based manufacturing processes thus reducing costs and enabling the widespread application of these innovative solar cell technology. With the availability of cheap, flexible OPVs it will be possible to provide electrical power wherever needed. Due to the mechanical flexibility and the low weight, OPVs offer completely new opportunities for mobile applications such as the integration of solar cells into outdoor clothing, caravan and trailer rooftops or for rooftop installations where no heavy loads can be applied due to structural limitations.

With focus on precise machining and evaluation of its limits in a continuous roll-to-roll process, 3D-Micromac supported the consortium in its task of developing efficient layouts for OPV modules. Furthermore 3D-Micromac developed laser machining processes for the embedded silver grids that were developed within X10D. Offering high transparency and conductivity, these metal grid electrodes were developed as a means of replacing common transparent electrodes like indium tin oxide (ITO).

Having a fully equipped roll-to-roll tool which incorporates pre-treatment, printing and coating as well as drying, laser scribing and lamination processes, 3D-Micromac also supported the task of up-scaling deposition techniques to form uniform films on a large area.

As a supplier of special purpose machinery for laser micro-machining but also for the production of flexible electronics 3D-Micromac uses results of X10D to improve its system and process technology. Knowledge gained within the project will be used in the design of new roll-to-roll laser processing equipment, especially in the selection of laser sources for processing special metal grid electrodes, interlayers and absorbing materials and in the development of the laser processes for micro-machining of these layers.

1.4.17 ARKEMA

Potential impact of the technology for OPV

The X10D project has allowed us, in collaboration with CEA to develop a gas barrier technology that should eventually lead to gas barrier films with outstanding performance/cost ratios. The potential impact of these films for OPV encapsulation is big with the well-known sensitivity of OPV cells to water vapour, and oxygen. Although we are still at an R&D stage, the technology has given some evidence of its upscalability to industrial processes.

Potential impact of the technology in other fields

From a wider point of view, the development of the gas barrier film technology within X10D, should allow to tackle other markets outside OPV; it can be hoped that the electronic device market will become available for some of the most performant gas barrier films we are developing.

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Dissemination activities

The X10D project has led to two scientific papers. These have been published by our partner CEA, after having them reviewed by Arkema's technical expert, and intellectual property department. Please refer to CEA's dissemination activities where the complete references of those two papers will be cited.

Arkema has participated with CEA at other dissemination activities, mainly at the LOPEC exhibition (see section 2. A2)

A patent application has been filed as a result of the work done within the X10D project. This patent, which is co-owned by CEA, and Arkema has been published, since the embargo date has been reached. The reference of the published application is given in section 2.B1

Exploitation of results

The results obtained through this project towards the development of encapsulation solutions for OPV cells are promising. We believe that the objectives, in the form of deliverables, have been attained. Nevertheless, in order to fully scale-up this technology to an industrial level, further R&D work needs to be done.

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2 Use and dissemination of foreground

2.1 Section A – dissemination measures

2.1.1 List of all scientific (peer reviewed) publications relating to the foreground of the project.

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers	Is/Will open access provided to this publication?
1	Determination of the Intrinsic Diode Parameters of Polymer Solar Cells	L. H. Slooff.	Energy Procedia	Volume 31	E-MRS Spring Meeting 2011	France	2012	11-20	doi: 10.1016/j.egypro.2012.11.159	yes
2	Thin gas-barrier silica layers from perhydropolysilazane obtained through low temperature curings: A comparative study	Stéphane Cros	Thin Solid Films	Volume 524			2012			
3	Cyclopentadienylruthenium pi-Complexes of Subphthalocyanines: A “Drop-Pin” Approach to Modifying the Electronic Features of Aromatic Macrocycles	Esmeralda Caballero	Angewandte Chemie International Edition	Vol.ume 51, Issue 45	Gesell-schaft Deutscher Chemiker	Germany	2012	11337 – 11342	doi: 10.1002/anie.201206111	yes

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4	Surface treatment patterning of organic photovoltaic films for low-cost modules	Roberto Pacios	Organic Electronics	Volume 14	Elsevier	The Netherlands	2012	430-435	Doi: 10.1016/j.orgel.2012.11.018	no
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers	Is/Will open access provided to this publication?
5	Post-functionalization of Helical Polyisocyanopeptides with Phthalocyanine Chromophores by 'Click'-Chemistry	I. López-Duarte	ChemPlus, Chem	Volume 77. Issue 8	John Wiley and Sons	Germany	2012	700-706	doi: 10.1002/cplu.201200087	no
6	Patterning of Organic Photo-voltaic Modules by Ultrafast Laser	Peter Kubis	Progress in Photovoltaics: Research and Applications	12/ year	John Wiley & Sons, Ltd.	online	2013	DOI: 10.1002/pip.2421		yes
7	Charge carrier transport and contact selectivity limit the operation of PTB7-based organic solar cells of varying active layer thickness	Antonio Guerrero	Journal of Materials Chemistry A	Issue 39	The Royal Society of Chemistry	United Kingdom	2013	12345-12354	doi: 10.1039/C3TA12358H	no
8	Gas barrier properties of solution processed composite multilayer structures for organic solar cells encapsulation		Solar Energy Materials & Solar Cells				2013	115 (2013) 93–99		

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9	Parameter Study for Polymer Solar Modules Based on Various Cell Lengths and Light Intensities	Slooff, L.H.	28th European Photovoltaic Solar Energy Conference and Exhibition Proceedings	No 43, March 1990			2013	pp. 2776 - 2780	10.4229/28th EUPVSEC2013-3DV.2.33	no
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers	Is/Will open access provided to this publication?
10	Photocurrent Enhancement from Diketopyrrolopyrrole Polymer Solar Cells through Alkyl-Chain Branching Point Manipulation	Iain Meager	Journal of the American Chemical Society`	2013, 135, 11537−11540	The American Chemical Society	United States	2013	11537−11540	DOI: 10.1021/ja406934j	no
11	Efficient truxenone-based acceptors for organic photovoltaics	Christian Nielsen	Journal of Materials Chemistry A	2013, 1, 73–76	Royal Society of Chemistry	United Kingdom	2013	73-76	DOI: 10.1039/C2TA00548D	no
12	Isostructural, Deeper Highest Occupied Molecular Orbital Analogues of Poly(3-hexylthiophene) for High-Open Circuit Voltage Organic Solar Cells	Hugo Bronstein	Chemistry of Materials	2013, 25, 4239−4249	The American Chemical Society	United States	2013	4239−4249	DOI: 10.1021/cm4022563	no
13	Thieno[3,2- b]thiophene-diketopyrrolopyrrole Containing Polymers for Inverted Solar Cells Devices with High Short Circuit Currents	Hugo Bronstein	Advanced Functional Materials	2013, 23: 5647–5654	John Wiley and Sons	United States	2013	5647–5654	DOI: 10.1002/adfm.201300287	no

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14	Post-Polymerization Ketalization for Improved Organic Photovoltaic Materials	Christian Nielsen	Macromolecules	2013, 46, 7727−7732	The American Chemical Society	United States	2013	7727−7732	DOI: 10.1021 /ma401474a	no
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers	Is/Will open access provided to this publication?
15	Improved Field-Effect Transistor Performance of a Benzotrithiophene Polymer through Ketal Cleavage in the Solid State	Christian Nielsen	ACS Applied Materials and Interfaces	2013, 5, 1806−1810	The American Chemical Society	United States	2013	1806−1810	DOI: 10.1021 /am303138q	no
16	Recent advances in transistor performance of polythiophenes	Christian Nielsen	Progress in Polymer Science	2013, 38, 2053– 2069	Elsevier	Netherlands	2013	2053– 2069	DOI: 10.1016/j.progpolymsci.2013.05.003	no
17	Charge carrier transport and contact selectivity limit the operation of PTB7-based organic solar cells of varying active layer thickness	Roberto Pacios	Journal of Materials Chemistry A	Issue 39	The Royal Society of Chemistry	United Kingdom	2013	12345-12354	doi: 10.1039/C3TA12358H	no
18	Roll-to-roll embedded conductive structures integrated into organic photovoltaic devices	H. J. van de Wiel	Nano-technology	Volume 24, Number 48	IOP Publishing	United Kingdom	2013	n.a.	doi:10.1088/0957-4484/24/48/484014	no

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19	Efficient tandem and triple-junction polymer solar cells	Weiwei Li	Journal of American Chemistry Society	Voulme 135, Issue 15	American Chemical Society	United States	2013	5529–5532	doi: 10.1021/ja401434x	no
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers	Is/Will open access provided to this publication?
20	Universal correlation between fibril width and quantum efficiency in diketopyrrolopyrrole-based polymer solar cells	Weiwei Li	Journal of American Chemistry Society	Voulme 135, Issue 50	American Chemical Society	United States	2013	18942−18948	doi: 10.1021/ja4101003	no
21	Synthesis, characterization and photophysical properties of a melamine-mediated hydrogen-bound phthalocyanine–perylenediimide assembly	Ángel J. Jimenez	Chem. Sci.	Volume 4, Issue 3	Royal Society of Chemistry	United Kingdom	2013	1064-1074	doi:10.1039/C2SC21773B	no
22	Tuning the Stability of Graphene Layers by Phthalocyanine-Based oPPV Oligomers Towards Photo- and Redoxactive Materials	L. Brinkhaus	Small	Volume 9, Issue 13	John Wiley and Sons	Germany	2013	2348–2357	doi: 10.1002/smll.201202427	
23	Trapping fullerenes with jellyfish-like subphthalocyanines	I. Sánchez-Molina	Chem. Sci.	Volume 4, Issue 3	Royal Society of Chemistry	United Kingdom	2013	1338-1344	doi: 10.1039/c3sc21956a.	

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24	Unraveling the peculiar modus operandi of a new class of solvatochromic fluorescent molecular rotors by spectroscopic and quantum mechanical methods	M. Koenig	Chem.Sci.	Volume 4,Issue 6	Royal Society of Chemistry	United Kingdom	2013	2502-2511	10.1039/c3sc50290b	
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers	Is/Will open access provided to this publication?
25	Self-assembly, host-guest chemistry, and photophysical properties of subphthalocyanine-based metalosupramolecular capsules	I. Sánchez-Molina,.,	J. Am. Chem. Soc.	Volume 135, Issue 28	American Chemical Society	United States	2013	10503–10511	10.1021/ja404234n	
26	Assembling a phthalocyanine and perylenediimide donor-acceptor hybrid through a platinum(II) diacetylide linker	A.J. Jiménez	Chem. Eur. J.,	Volume 19,Issue 43	Wiley-VCH	Germany	2013	14506-14514	10.1002/chem.201301630	
27	Synthesis and Ultrafast Time Resolved Spectroscopy of Peripherally Functionalized Zinc Phthalocyanine bearing Oligothienylene-ethynylene Subunits	O. O. Adegoke	J. Phys. Chem. C	Volume 117,Issue 40	American Chemical Society	United States	2013	20912-20918	10.1021/jp404406b	
28	R2R embedded conductive structures integrated into organic photovoltaic devices	H.J. van de Wiel	Nanotechnology	No 24, 484014, Year 2013	IOP Science		2013	484014		no

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NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers	Is/Will open access provided to this publication?
29	High Precision Processing of Flexible P3HT: PCBM Modules with Geometric Fill Factor over 95 %	Peter Kubis	Organic Electronics	12/year	Elsevier	online	2014	Vol. 15, 2256–2263		yes
30	Air-processed organic tandem solar cells: Toward competitive operating lifetimes	Jens Adams	Energy & Environmental Science	12/ year	Royal Society of Chemistry	online	2014	DOI: 10.1039/C4EE02582B		no
31	Decreased Recombination Through the Use of a Non-Fullerene Acceptor in a 6.4% Efficient Organic Planar Heterojunction Solar Cell		Advanced Energy Materials	Volume 4, Issue 8, June 3, 2014	John Wiley and Sons	United States	2014	n.a.	doi: 10.1002/aenm.201301413	no
32	8.4% efficient fullerene-free organic solar cells exploiting long-range exciton energy transfer	Kjell Cnops	Nature Communications	Article nr: 3406 07 March 2014	Nature Publishing Group	United Kingdom	2014	n.a.	doi:10.1038/ncomms4406	no
33	Describing the light intensity dependence of polymer:fullerene solar cells using an adapted Shockley diode model.	Slooff, L.H.	Phys Chem Chem Phys.	16(12)			2014	5732-5738	doi: 10.1039/c3cp55293d	no

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34	Electron-deficient truxenone derivatives and their use in organic photovoltaics	Christian Nielsen	Journal of Materials Chemistry A	2014,2, 12348-12354	Royal Society of Chemistry	United Kingdom	2014	12348-12354	DOI: 10.1039 /C4TA01653J	yes
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers	Is/Will open access provided to this publication?
35	Decreased Recombination Through the Use of a Non-Fullerene Acceptor in a 6.4% Efficient Organic Planar Heterojunction Solar Cell		Advanced Energy Materials	Volume 4, Issue 8, June 3, 2014	John Wiley and Sons	United States	2014	n.a.	doi: 10.1002/aenm.201301413	no
36	Describing the light intensity dependence of polymer:fullerene solar cells using an adapted Shockley diode model.	L. H. Slooff.	Physical Chemistry Chemical Physics	Issue 12	Royal Society of Chemistry	United Kingdom	2014	5732-5738	doi: 10.1039/c3cp55293d	no
37	Series vs parallel connected organic tandem solar cells: Cell performance and impact on the design and operation of functional modules	Roberto Pacios	Solar Energy Materials and Solar Cells	Volume 130	Elsevier	The Netherlands	2014	495-504	Doi:10.1016/j.solmat.2014.07.047	
38	Inverted vs standard PTB7:PC70BM organic photovoltaic devices. The benefit of highly selective and extracting contacts in device performance	Roberto Pacios	Organic Electronics	Volume 15	Elsevier	The Netherlands	2014	2756-2762	Doi: 10.1016/j.orgel.2014.08.008	no

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39	Homocoupling defects in diketopyrrolopyrrole-based copolymers and their effect on photovoltaic performance	Koen Hendriks	Journal of American Chemistry Society	Voulme 136, Issue 31	American Chemical Society	United States	2014	11128−11133	doi: 10.1021/ja505574a	no
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers	Is/Will open access provided to this publication?
40	Small-Bandgap Semiconducting Polymers with High Near-Infrared	Koen Hendriks	Journal of American Chemistry Society	Voulme 136, Issue 34	American Chemical Society	United States	2014	12130−12136	doi: 10.1021/ja506265h	no
41	Effect of the fibrillar microstructure on the efficiency of high molecular weight diketopyrrolopyrrole based polymer solar cells	Weiwei Li	Advanced Materials	Volume 26, Issue 10	Wiley VCH	Germany	2014	1565–1570	doi: 10.1002/adma.201304360	no
42	Wide band gap diketopyrrolopyrrole-based, conjugated polymers incorporating biphenyl units applied in polymer solar cells conjugated polymers incorporating biphenyl units	Weiwei Li	Chemical Communications	Volume 50, Issue 6	Royal Society of Chemistry	United Kingdom	2014	679-681	doi: 10.1039/c3cc47868h	no
43	Subphthalocyanines, Subporphyrazines and Subporphyrins: Singular non-planar aromatic systems"	C. G. Claessens	Chem. Rev.	Volume 114, Issue 4	American Chemical Society	United States	2014	2192−2277	10.1021/cr400088w	

44	Synthesis and characterization of bis-[PcRu(CO)][Ru2(ap)4(C≡CC5H4N)2]	M. Manowong	J. Porp.Phth.	Volume 18,Issue 1-2	World Scientific		2014	49-57	10.1142/S10884246135012 28	
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers	Is/Will open access provided to this publication?
45	Ruthenoarenes versus Phenol Derivatives as Axial Linkers for Subporphyrazine Dimers and Trimers	Esmeralda Caballero	Chem. Eur. J.	Volume 20,Issue 21	Wiely-VCH	Germany	2014	6518-6525	10.1002/chem.201304622	
46	The reorganization energy of intermolecular hole hopping between dyes anchored to surfaces	D. Moia	Chem. Sci.	Volume 5, Issue 1	Royal Society of Chemistry	United Kingdom	2014	281-290	10.1039/c3sc52359d	
47	Decreased Recombination Through the Use of a Non-Fullerene Acceptor in a 6.4% Efficient Organic Planar Heterojunction Solar Cell	Bregt Verreet	Advanced Energy Materials	Volume 4, Issue 8, June 3, 2014	John Wiley and Sons	United States	2014	1301413/1-1301413/8	doi: 10.1002/aenm.201301413	no
48	Digital Fabrication of Organic Solar Cells by Inkjet Printing using non-Halogenated Solvents	T. M. Eggenhuisen	Solar Energy Material and Solar Cells	Submitted	Elsevier		2014			no

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49	High Efficiency, Fully Inkjet Printed Organic Solar Cells with Freedom of Design	T. M. Eggenhuisen	Advanced Materials	In preparation	Whiley		2014			no

2.1.2 List of all dissemination activities

NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
1	poster	ECN	28th European Photovoltaic Solar Energy Conference and Exhibition	26.02.2010	Paris	Scientific community	100-500	Worldwide
2	Conference	Tomás Torres (UAM)	Gesellschaft Deutcher Chemiker Festkolloquium Molekulare Materialen	21.10.2011	Tuebingen, Germany	Scientific Community		International
3	Conference	Tomás Torres (UAM)	4rd Yonsei International Symposium on Nano-Bio Molecular Assembly	29.10.2011	Seoul, Korea	Scientific Community		International
4	Presentation	Tomás Torres (UAM)	Invited lecture at the University of Tokyo	07.11.2011	Tokyo, Japan	Scientific Community		Japan
5	Presentation	Tomás Torres (UAM)	Invited lecture at University of Science and Technology Beijing	17.11.2011	Beijing, China	Scientific Community		China
6	Presentation	Tomás Torres (UAM)	Invited lecture at Oxford University	23.11.2011	Oxford, UK	Scientific Community		UK

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7	Conference	Tomás Torres (UAM)	International Conference Next Generation Solar Energy	13.12.2011	Erlangen, Germany	Scientific Community		International
8	Conference	Paul Blom	MRS Fall meeting 2011	27 Nov – 02 Dec 2011	Boston	Scientific Community		
9	Website	IK4-IKERLAN	http://www.ikerlan.es/es/que-investigamos/proyectos/x10d	2012	Spain	Medias		Worldwide
10	Conference	Tomás Torres (UAM)	International Symposium on Macrocyclic and Supramolecular Chemistry, ISMCS-7	02.02.2012	Dunedin, New Zealand	Scientific Community		International
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
11	Conference	Tomás Torres (UAM)	International Symposium on Electronic Functional Molecules East China University of Science and Technology	12.03.2012	Shanghai, China	Scientific Community		International
12	Conference	Tomás Torres (UAM)	The Scripps Research Institute, Chemistry Lecture Series	22.03.2012	La Jolla, California, USA	Scientific Community		US
13	Conference	Tomás Torres (UAM)	243rd ACS National Meeting, San Diego, California, USA	29.03.2012	San Diego, USA	Scientific Community		International
14	Workshop: invited talk	Christoph Brabec	Durability of thin film solar cells	04.04.2012	Zürich, EMPA, Switzerland			
15	Presentation	Tomás Torres (UAM)	Invited lecture at University of Texas at El Paso, College of Science	05.04.2012	El Paso, TX, USA	Scientific Community		US
16	Presentation	Tomás Torres (UAM)	Invited lecture at Gebze Institute of Technology	01.06.2012	Çayirova, Gebze-Kocaeli, Turkey	Scientific Community		Turkey

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17	Conference	Tomás Torres (UAM)	Seventh International Conference on Porphyrins and Phthalocyanines, (ICPP-7)	02.07.2012	Jeju, Korea	Scientific Community		International
18	Conference	Tomás Torres (UAM)	The 2nd symposium on “Carbon Nanoforms”, National Institute of Advanced Industrial Science and Technology (AIST)	09.07.2012	Tsukuba, Japan	Scientific Community		International
19	Workshop	Tomás Torres (UAM)	III Brazil-Spain Workshop on Organic Chemistry, Instituto de Química, UNICAMP, Campinas, São Paulo, Brazil	05.09.2012	Campinas, São Paulo, Brazil	Scientific Community		Brazil and Spain
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
20	Conference: invited talk	Christoph Brabec		10.10.2012	Plastic Elec. 2012, Dresden, Germany	Scientific Community & Industry	app. 300	International conference, world-wide
21	Conference: invited talk	Christoph Brabec		12.10.2012	Erlangener Kunststofftage, Erlangen	Scientific Community & Industry		German community
22	Conference	Ronn Andriessen	Sunday	07. Nov 12	‘s Hertogenbosch	Scientific Community		
23	Interview	Tomás Torres (UAM)	http://www.rtve.es/alacarta/audios/uned/uned-nanociencia-espana-investigaciones-perspectivas-04-12-12/1603798	04.12.2012	Madrid, Spain	Scientific Community and civil society		Spain
24	Conference	Yulia Galagan	IEEE PVSC	03 – 08 June 2012	Austin	Scientific Community		

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25	Trade fair	3D-MM	drupa	03.-16.05.2012	Dortmund/Germany	Scientific Community, Industry	-	-
26	Conference	Jan Gilot	OPV summer school – SimOEP 2012	10 – 14 June 2012	Oliva	Scientific Community		
27	Conference	Yulia Galagan	GSAS, Session on Organic solar cells	17 – 21 Sept 2012	Taiwan	Scientific Community		
28	Conference/ symposium: oral presentation	Monika Voigt	Solar production for the future: the route from sheet-to-sheet to inline manu-facturing	17.-18.10.2012	ILACOS, Dresden, Germany	Scientific Community & Industry	app. 300	International conference, world-wide
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
29	Conference	Ronn Andriessen	LOPE-C	19 – 21 June 2012	Munchen	Scientific Community		
30	Trade fair	3D-MM	LOPE-C	19.-21.06.2012	Frankfurt/Germany	Scientific Community, Industry	-	-
31	Conference	Ronn Andriessen	CPTIC 2012	20 – 22 Mar 2012	Shanghai	Scientific Community		
32	Conference	Nadia Grossiord	s-Polymat 2012	20 – 23 May 2012	Rolduc	Scientific Community		
33	Thesis	IK4-IKERLAN	Hybrid Photovoltaic Devices based on Organic Semiconductor Polymers and Inorganic Nanostructured Electrodes	2009-2012	The University of the Basque Country (Spain)	Scientific Community		Worldwide

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34	Conference: oral presentation	Gebhard Matt		22.-24.05.2012	TPE 2012, Rudolstadt, Germany	Scientific Community & Industry		
35	Conference	Ronn Andriessen	PVSEC 2012	24 – 27 Sept 2012	Frankfurt	Scientific Community		
36	Conference	Jan Gilot	MRS Fall meeting 2012	26 – 30 Nov 2012	Boston	Scientific Community		
37	Conference: invited talk	Christoph Brabec		26.-30.11.2012	MRS Fall Meeting, Boston,US, 2012	Scientific Community & Industry	app. 500	International conference, world-wide
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
38	Conference: invited talk	Christoph Brabec		6.-7.12.2012	ISOS 5, Eindhoven	Scientific Community & Industry	app. 300	International conference, world-wide
39	Conference	Ronn Andriessen	Plastic Electronics	9 – 11 Okt 2012	Dresden	Scientific Community		
40	Work shop: invited talk	Monika Voigt	(in german): Solar factory of the future: optimization and upscaling of thin film solar manufacturing from lab to industrial mass manufacturing	9.-10.10.2012	FMP, Erlangen/ Tennenlohe, Germany	Industry	app. 50	German community
41	Presentation, flyers		Symposium Organics & Printed Electronics	Nov 23, 2012	Eindhoven	Scientific Community, Industry	~100	The Netherlands, Germany, Belgium

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42	Presentation	Tomás Torres (UAM)	Meeting at the Federal Institute for Materials Research and Testing, Adlerhof, Berlin.	11.03.2013	Adlerhof, Berlin, Germany	Scientific Community		International
43	Conference	Christian Nielsen	Truxenone-based Small Molecule Acceptors for Efficient Organic Photovoltaic Devices	03. Apr 13	San Francisco, United States	Scientific Community		
44	Conference	Christian Nielsen	Electron-Deficient Motifs and Their Use in Both Donor- and Acceptor-Type Materials for Organic Photovoltaics	22. Apr 13	San Francisco, United States	Scientific Community		
45	Invited lecture	Tomás Torres (UAM)	223rd Meeting of the Electrochemical Society (ECS)	14.05.2013	Toronto, Canada	Scientific Community		International
46	Invited lecture	Tomás Torres (UAM)	4th Georgian Bay International Conference on Bioinorganic Chemistry (CanBIC-4)	24.05.2013	Ontario, Canada	Scientific Community		International
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
47	Invited lecture	Tomás Torres (UAM)	Scientific School on Nanotechnology, Kazan National Research Technological University	05.06.2013	Kazan, Republic of Tatarstan, Russian Federation	Scientific Community		Kazan
48	Invited lecture	Tomás Torres (UAM)	International Conference on "Solar Energy for World Peace"	19.08.2013	Istanbul , Turkey	Scientific Community		International
49	Conference	Iain McCulloch	Development of Versatile Semiconducting Polymers	25. Aug 13	San Diego, United States	Scientific Community		

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NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
50	Invited lecture	Tomás Torres (UAM)	International Conference on Advanced Polymeric Materials (ICAPM) Mahatma Gandhi University	12.10.2013	Kottayam, Kerala, India	Scientific Community		International
51	Printed Electronics USA 2013	Peter Willaert	Strategies towards more transparent more conductive electrodes	Nov. 13	Santa Clara	Sientific + Industrial		USA
52	Conference	Iain McCulloch	Development of Semiconducting Polymers	28. Nov 13	Aix en Provence, France	Scientific Community		
53	Conference	Heliatek	NanoMat Symposium "Nano Meets Optics and Electronics"	26.-27.09.2013	Karlsruhe / Germany	Scientific Community, Industry	>200	all EU
54	Advanced Functional & Industrial Printing 2013	Bavo Muys	Conductive Polymer and Metallic new inks for Functional Printing	March 2013	Düsseldorf	Sientific + Industrial		Europe
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
55	Conference	Christian Nielsen	New Electron-Deficient Motifs and Their Use in Push-Pull Type Donor Polymers for Organic Photovoltaics	02 December 2013	Boston, United States	Scientific Community		
56	Conference	Iain Meager	Alkyl chain and polymer backbone modification in thieno[3,2-b]thiophene based diketopyrrolopyrrole polymers for high performance OPV and FET applications	10 December 2013	Loughborough, UK	Scientific Community		

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57	Conference: Poster	Jens Adams	Light Soak investigations on degraded P3HT:PCBM solar cells	10.-12.12.2013	ISOS6, Chambery, France	Scientific Community & Industry	app. 100	International conference, world-wide
58	Conference	Yulia Galagan	ISOS-6	10-12/12 2013	Chambery (France)	Scientific Community		
59	Trade fair	3D-MM	LOPE-C	11.-13.06.2013	Munich/Germany	Scientific Community, Industry	-	-
60	Exhibition	Ronn Andriessen	LOPE-C	11-13/06 2013	Munich (Germany)	Industry		
61	Conference	Thijs Slaats	ECS	11-13/09 2013	Mons (Belgium)	Scientific Community		
62	Conference	Monika Voigt	Tailoring green formulations: printing and upscaling of inverted organic solar cells	16.-21.6.2013	IEEE, Tampa, Florida, USA	Scientific Community & Industry	app. 200	International conference, world-wide
63	Conference: oral presentation	Peter Kubis		18.-20.3.2013	FemtoMat, Mauterndorf, Austria	Scientific Community & Industry		
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
64	Conference	Iain McCulloch	Semiconducting Polymers for Transistors and Solar Cells	27 May 2013	Strasbourg, France	Scientific Community		
65	Exhibition	Ronn Andriessen, Jan Gilot	PVSEC	30/9-04/10 2013	Paris (France)	Industry		

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66	Conference	Ronn Andriessen	Plastic Electronics	8-10/10 2013	Dresden (Germany)	Scientific Community		
67	Conference MRS Spring meeting 2013	TUE	Improved materials for single and tandem junction polymer solar cells	April 1-5, 2013	San Francisco	Science & Technology	150	World
68	Conference Solar Energy for World Peace	TUE	Improved materials for single and tandem junction polymer solar cells	August 17-19, 2013	Istanbul	Science & Technology	200	World
69	Press Release	Tamara Eggenhuisen	World's first all-inkjet-printed OPVs offer flexibility for fast product development	December 2013	http://www.holstcentre.com/NewsPress/NewsList/allInkjetPrintedOPV.aspx			
70	Conference Next Generation Solar Energy	TUE	Multijunction polymer solar cells	December 9-11, 2013	Erlangen	Science	150	Europe & US
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
71	LOPE-C 2013	Peter Willaert	OrgaconGrid - Strategies towards more transparent and higher conductivity flexible electrodes	June 2013	München	Sientific + Industrial		Worlwide

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72	Conference F-pi-11	TUE	Improved materials for single and tandem junction polymer solar cells	June 2-7, 2013	Arcachon	Science & Technology	100	Europe
73	Conference ICMAT 2013	TUE	Improved materials for single and tandem junction polymer solar cells	June 30 – July 5, 2013	Singanope	Science & Technology	100	World
74	Internal presentations	Frank Louwet	Strategies towards more transparent and higher conductivity, flexible electrodes	March 2013		Industrial		Japan
75	Press Release	Tamara Eggenhuisen	Reducing ecological footprint of OPV production	May 2013	http://www.holstcentre.com/NewsPress/NewsList/NonChlorinatedOPV.aspx			
76	Conference E-MRS 2013	TUE	Improved materials for single and tandem junction polymer solar cells	May 27-30, 2013	Strasbourg	Science & Technology	100	Europe
77	Conference Plastic Electronics Conference	TUE	Improved materials for single and tandem junction polymer solar cells	October 8-11, 2013	Dresden	Science & Technology	75	Europe
78	Conference Talk at MRS Fall Meeting	Heliatek	"Towards Roll-to-Roll Mass Production of Efficient Organic Vacuum Deposited PIN-Tandem Solar Cells"	01.-06.12.2013	Boston / US	Scientific Community, Industry	>200	worldwide
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed

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79	Booth at exhibition	Holst Centre	LOPE-C	11-13/06 2013	Munich (Germany)			
80	Oral presentation	Holst Centre	ECS	11-13/09 2013	Mons (Belgium)			
81	Booth at exhibition + visiting conference	Holst Centre	PVSEC	30/9-04/10 2013	Paris (France)			
82	Invited talk	Holst Centre	Plastic Electronics	8-10/10 2013	Dresden (Germany)			
83	Invited talk	Holst Centre	ISOS-6	10-12/12 2013	Chambery (France)			
84	Exposition of demonstrator s	Holst Centre	Organext	03-04/06 2013	Hasselt (Belgium)			
85	Oral presentation	Holst Centre	IEEE:PVSC	09-13/06 2013	Denver			
86	Invited lecture	Tomás Torres (UAM)	Division of Energy and Fuels, Nanostructured Materials for Solar Energy Conversion and Storage, 247th ACS National Meeting	18.03.2014	Dallas, Texas, USA	Scientific Community		International
87	Invited lecture	Tomás Torres (UAM)	Chemistry Department, The University of Texas at Austin	20.03.2014	Austin, USA	Scientific Community		USA

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NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
88	Invited lecture	Tomás Torres (UAM)	Department of Chemistry, University of California Santa Barbara, California Nanosystems Institute	21.03.2014	Santa Barbara, USA	Scientific Community		USA
89	Invited lecture	Tomás Torres (UAM)	Facultad de Química, Universidad Nacional Autónoma de Mexico	26.03.2014	México	Scientific Community		Mexico
90	Printed Electronics Europe 2014	Peter Willaert	Expand your PE possibilities with Orgacon™ printable conductors	Apr. 14	Berlin	Sientific + Industrial		Worldwide
91	Conference	Iain Meager	Thieno[3,2-b]thiophene based diketopyrrolopyrrole and isoindigo polymers for high performance OFET and OPV applications	15. Apr 14	Brussels, Belgium	Scientific Community		
92	Invited lecture	Tomás Torres (UAM)	Symposium B: Organic and Inorganic Materials for Dye-Sensitized Solar Cells, 2014 MRS Spring Meeting	24.06.2014	San Francisco, California, USA	Scientific Community		International
93	Plenary lecture	Tomás Torres (UAM)	3rd Solar Technologies go Hybrid (SolTech) Meeting	28.06.2014	Wildbad Kreuth, Germany	Scientific Community		International
94	3th International Digital Congress 2014	Guido Desie	Printing Transparent Flexible Conductors for Textiles	Aug. 14	Gent	Sientific + Industrial		Worldwide

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95	Article in popular press	IK4-IKERLAN	http://www.noodls.com/viewNoodl/24919071/euskal-herriko-unibertsitatea/2014-09-01-future-solar-panels	01.09.2014	Spain	Medias		Worldwide
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
96	Article in popular press	IK4-IKERLAN	http://www.prentsa.ehu.es/p251-content/es/contenidos/noticia/20140901_ikerne_etxebarria/es_etxebarr/20140901_ikerne_etxebarria.html	01.09.2014	Spain	Medias		Spain
97	Article in popular press	IK4-IKERLAN	http://www.berria.eus/paperekoa/1846/016/001/2014-09-07/poltsan_eskuko_telefonoa_sartu_eta_kargatuz_joateko_era_izango_da.htm	07.09.2014	Spain	Medias		Spain
98	Article in popular press	IK4-IKERLAN	http://www.diariovasco.com/sociedad/201409/11/paneles-solares-para-futuro-20140911000725.html	11.09.2014	Spain	Medias		Spain
99	Conference	Iain Meager	Thieno[3,2-b]thiophene as a building block in organic electronics; diketopyrrolopyrrole and isoindigo polymers and small molecules for high performance OFET and OPV applications	03 July 2014	Turku, Finland	Scientific Community		
100	Exhibition	Yulia Galagan	Organext	03-04/06 2014	Hasselt (Belgium)	Scientific Community		
101	Conference	Jan Gilot	IEEE:PVSC	09-13/06 2014	Denver (USA)	Scientific Community		

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102	Thesis	IK4-IKERLAN	Mini-Modules and Tandem Organic Solar Cells: Strategies to improve device efficiency	2011-2014	Bilbao (Spain)	Scientific Community		Worldwide
103	Conference	Yulia Galagan	TPE-14	20-22/05 2014	Ilmenau (Germany)	Scientific Community		
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
104	Conference: Oral Presentation	Luca Lucera	Design and Realization of Highly Efficient oPV Modules by Combining Sub-10 Micron Laser Patterning with High Precision Slot Die Coating	21.-25.4.2014	MRS Spring, San Francisco, California, US	Scientific Community & Industry	app. 300	International conference, world-wide
105	Trade fair	3D-MM	LOPE-C	26.-28.05.2014	Munich/Germany	Scientific Community, Industry	-	-
106	Exhibiton. Joint exhibition with CEA, X10D poster and flyers	CEA	LOPEC 2014	26.-28.05.2014	Munich	Scientific Community	Large (exhibition)	European
107	Conference	Iain McCulloch	Versatile Semiconducting Polymers	30 June 2014	Turku, Finland	Scientific Community		
108	Conference: oral presentation	Monika Voigt	Printed and upscaled polymer solar cells and modules by using non-halogenated solvents and via laser-ablation for structuring	30.6.-5.7.2014	ICSM, Turku, Finland	Scientific Community & Industry	app. 100	International conference, world-wide
109	Conference	Jan Gilot	ESREF	30/09 2014	Berlin (Germany)	Scientific Community		

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110	Conference: oral presentation	Jens Adams	Loss analysis on organic solar cells and modules by using contactless and non-destructive infrared lock in imaging techniques	6.-10.7.2014	ISFOE 14, Thessaloniki, Greece	Scientific Community & Industry	app. 100	International conference, world-wide
111	Conference: oral presentation	Frank Fecher	Temperature simulation of shunts in OPV cells	6.-10.7.2014	ISFOE 14, Thessaloniki, Greece	Scientific Community & Industry	app. 100	International conference, world-wide
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
112	Conference: oral presentation	Monika Voigt	Flexible upscaled & printed organic solar modules by using non-chlorinated solvents and R2R compatible methods combined with laser patterning	6.-10.7.2014	ISFOE 14, Thessaloniki, Greece	Scientific Community & Industry	app. 100	International conference, world-wide
113	Conference SPIE Photonics Europe	TUE	Multijunction polymer solar cells and water splitting	April 14 – 17, 2014	Brussels	Science & Technology	100	World
114	Exhibition, flyers		Inprint	April 8-10, 2014	Hannover	Scientific community, Industry, Media, Other	7000	Germany, UK, Italy, Poland, The Netherlands, Belgium, Austria, France, Switzerland
115	Conference SPIE 2014 – Organic	TUE	Materials and device architectures for multi-junction polymer solar cells	August 17-21, 2014	San Diego	Science & Technology	100	World

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	Photovoltaics XV							
116	Conference HOPV 2014	TUE	Converting Solar Energy with Organic Materials	May 11-14, 2014	Lausanne	Science & Technology	500	World
117	Seminar Talk at Imperial College	Heliatek	"Vacuum deposited organic solar cells: From challenging science to commercial opportunities"	14.-15.01.2014	London / GB	Scientific Community	20	UK
NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
118	Poster contribution at conference "Hybrid and Organic Photovoltaic 2014"	Heliatek	"Outdoor Measurements and Stability of Vacuum Deposited Small Molecule Organic Photovoltaics	10.-15.05.2014	Lausanne / CH	Scientific Community, Industry	2000	worldwide
119	Conference Talk at LOPEC 2014	Heliatek	"Towards roll-to-roll mass production of efficient organic vacuum-deposited p-i-n tandem solar cells"	26.-27.05.2014	Munich / DE	Industry, Scientific Community , Policy makers	2000	all EU
120	Intersolar Europe	Heliatek	Presentation of project at Heliatek booth	02.-06.06.2014	Munich / DE	Industry, Scientific Community , Policy makers	6000	worldwide

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NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
121	Contributed talk at Photonics21 - WG4 meeting	Heliatek	"Next topics for OPV research and industrialisation"	01.-03.07.2014	Brussels / BE	Industry, Scientific Community	200	all EU
122	Conference Talk at SPIE2014	Heliatek	"Organic Solar Cells: From lab to Roll-to-Roll production"	17.-21.08.2014	San Diego / US	Undustry, Scientific Com.	500	worldwide
123	Invited talk	Holst Centre	TPE-14	20-22/05 2014	Ilmenau (Germany)			
124	Exhibition booth + Workshop presentation	Imec	Industrial Technologies 2014	9-11 April 2014	Athens / Greece	Industry, Scientific Community , Policy makers	200	EU
125	Oral presentation	imec	ICCG10	22-26 June 2014	Dresden / Germany	Industry, Scientific Community	120	Worldwide
126	Exhibition Booth	imec	EU-PVSEC	22-25 September 2014	Amsterdam / NL	Industry, Scientific Community , Policy makers	+200	Worldwide

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127	Press Release	UNAM	Article about the talk of Prof. Tomás Torres at the UNAM Journal "Gaceta Facultad de Química", Universidad Nacional Autónoma de México			University Community And civic society		Mexico
128	Press release	imec	Project launch	January 2012		Industry, Scientific Community , Policy makers		Worldwide
129	Press release	imec	Novel fullerene-free OPV concept	January 2014		Industry, Scientific Community , Policy makers		Worldwide

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3 Report on societal implications

A	General Information
Grant Agreement Number:	287818
Title of Project:	X10D - Efficient, low-cost, stable tandem organic devices
Name and Title of Coordinator	Dr. Tom Aernots

B	Ethics		
1.	**Did you Project undergo an Ethic Review (and/or Screening?)** • If Yes: have you describe the Progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports?		
Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/ Final Project Reports under the Section 3.2.2 *"Work Progress and Achievements"*			Yes
		x	No
2.	**Please indicate whether your Project involved any of the following issues (tick box)**	**No/ Yes**	
Research on Humans			
•	Did the Project involve children?	**N**	
•	Did the Project involve patients?	**N**	
•	Did the Project involve persons not able to give consent?	**N**	
•	Did the Project involve adult healthy volunteers?	**N**	
•	Did the Project involve Human genetic material	**N**	
•	Did the Project involve Human biological samples?	**N**	
•	Did the Project involve Human data collection?	**N**	
Research on Human Embryo/ Foetus			
•	Did the Project involve Human embryos?	**N**	
•	Did the Project involve Human Foetal Tissue/Cells?	**N**	
•	Did the Project involve Human Embryonic Stem Cells (hESCs)?	**N**	
•	Did the Project on Human Embryonic Stem Cells involve cells in culture?	**N**	
•	Did the Project on Human Embryonic Stem Cells involve the derivation of cells from Embryos?	**N**	
Privacy			
•	Did the Project involve processing of genetic information or personal data (eg. health, sexual, lifestyle, ethnicity, political opinion, religious or philosophical conviction?	**N**	

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• Did the Project involve tracking the location or observation of people?	**N**
Research on Animals	
• Did the Project involve research in animals?	**N**
• Were those animals transgenic small laboratory animals?	**N**
• Were those animals transgenic farm animals?	**N**
• Were those animals cloned farm animals?	**N**
• Were those animals non-human primates?	**N**
Research involving Developing Countrys	
• Did the Project involve the use of local resources (genetic, animal, plant etc)	**N**
• Did the Project of benefit to local community (capacity building, access to healthcare, education etc)	**N**
Dual Use	
• Research having direct military use?	Yes: ; No: **x**
• Research having the potential for terrorist abuse	**N**

C	**Workforce Statistics**	
3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).		
Type of Position	**Number of Women**	**Number of Men**
Scientific Coordinator		**1**
Work package leaders		**5**
Experienced researchers (i.e. PhD holders)	**+10**	**+10**
PhD Students	**+5**	**+5**
Other		
4. How many additional researchers (in companies and universities) were recruited specifically for this project?		
Of which, indicate the number of men:		

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D	Gender Aspects		
5.	Did you carry out specific Gender Equality Actions under the project?		Yes
		x	No

6. Which of the following actions did you carry out and how effective were they?

		Not at all effective				Very effective
o	Design and implement an equal opportunity policy	o	o	o	o	o
o	Set targets to achieve a gender balance in the workforce	o	o	o	o	o
o	Organise conferences and workshops on gender	o	o	o	o	o
o	Actions to improve work-life balance	o	o	o	o	o
o	Other:					

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

	Yes- please specify	
x	No	

E	Synergies with Science Education	
8.	Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?	
x	Yes- please specify	Summer school on OPV organized
	No	
9.	Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?	
	Yes- please specify	
x	No	

F	Interdisciplinarity	
10.	Which disciplines (see list below) are involved in your project?	
o	Main discipline[2]:	1.2
o	Associated discipline[1]	1.3
o	Associated discipline[1]:	2.2

[2] Insert number from list below (Frascati Manual).

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***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES
1.1. Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
1.2. Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3. Chemical sciences (chemistry, other allied subjects)
1.4. Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
1.5. Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2. ENGINEERING AND TECHNOLOGY
2.1. Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
2.2. Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialized technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES
3.1. Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
3.2. Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
3.3. Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES
4.1. Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
4.2. Veterinary medicine

5. SOCIAL SCIENCES
5.1. Psychology
5.2. Economics
5.3. Educational sciences (education and training and other allied subjects)
5.4. Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES
6.1. History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
6.2. Languages and literature (ancient and modern)
6.3. Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]

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G	Engaging with Civil society and policy makers		
	11a. Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*		Yes
		x	No

H	Use and dissemination		
14.	**How many Articles were published/accepted for publication in peer-reviewed journals?**		49
	To how many of these is open access[3] provided?		**4**
	How many of these are published in open access journals?		**4**
	How many of these are published in open repositories?		
	To how many of these is open access not provided?		**45**
	Please check all applicable reasons for not providing open access:		
x	publisher's licensing agreement would not permit publishing in a repository		
	no suitable repository available		
	no suitable open access journal available		
	no funds available to publish in an open access journal		
	lack of time and resources		
x	lack of information on open access		
	other[4]: ……………		
15.	**How many new patent applications ('priority filings') have been made?** *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**4**
16.	**Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).**	Trademark	
		Registered design	
		Other	
17.	**How many spin-off companies were created / are planned as a direct result of the project?**		
	Indicate the approximate number of additional jobs in these companies:		

[3] Open Access is defined as free of charge access for anyone via Internet.

[4] For instance: classification for security project

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18.	**Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:**		
	Increase in employment, or		In small & medium-sized enterprises
	Safeguard employment, or		In large companies
	Decrease in employment,		None of the above / not relevant to the project
x	Difficult to estimate / not possible to quantify		
19.	**For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:**		
Indicate figure:			
x	Difficult to estimate / not possible to quantify		

I	**Media and Communication to the general public**		
20.	**As part of the project, were any of the beneficiaries professionals in communication or media relations?**	o	Yes
		•	No
21.	**As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?**	O	Yes
		•	No

22. Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

Press Release	●	Coverage in specialist press	●
Media briefing	o	Coverage in general (non-specialist) press	o
TV coverage / report	●	Coverage in national press	●
Radio coverage / report	o	Coverage in international press	●
Brochures /posters / flyers	●	Website for the general public / internet	●
DVD /Film /Multimedia	●	Event targeting general public (festival, conference, exhibition, science café)	o

23. In which languages are the information products for the general public produced?

Language of the coordinator		English	x	Other language(s)	

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