1. Publishable summary

1.1 Executive Summary

The main objective of the Nanophotonics for Energy Efficiency Network of Excellence was the promotion of nanophotonics research in energy-efficient applications by bringing together different laboratories and research groups across Europe. The Consortium is formed by 9 institutions in 6 European countries and mobilises over 130 scientists, engineers, technicians and managers in the field.

Although not initially foreseen in the contract, the project has been expanded to actively involve the nanophotonics for energy efficiency community at large by creating an Associate Membership scheme and opening up all project activities to Associate Members. The number of Associate Members has steadily increased since the introduction of the scheme in year 2 of the project up to a total of 57 at project end. It is worth mentioning that over 90% of those members have been actively involved in project activities and that approximately one third of the Associate Members are from industry. The project has also established an online community of interest on nanophotonics for energy efficiency through existing and well-established online platforms: the Nanophotonics for Energy Efficiency group in LinkedIn (http://www.linkedin.com/groups/Nanophotonics-Energy-Efficiency-3705807) with 426 members at the time of writing of this report, the @NanoOptics account in twitter with 226 followers, and the Nanophotonics for Energy Efficiency page at Facebook https://www.facebook.com/NanoPhotonics4Energy with 1238 followers. All these will continue operations beyond project duration.

One of the most effective mechanisms to promote participation by Associate Members has been the Seed Proposal scheme. The main objective of the scheme is to encourage uptake of the key research topics by providing seed funding for short-term (3-6 months) exploratory research projects to be carried out by 2 or more partners within the consortium or including associated members. A total of 7 calls for project proposals have been published within the project. 65 proposals were submitted and 29 of them selected for funding. 42 different institutions have participated in the calls, 14 of them industrial. The results obtained in the seed projects have had significant impact, both scientific (e.g. one of the papers has been the most cited paper in

2011 in the prestigious Nano Letters journal, another one selected among the best in Advanced Optical Materials and several ones became cover page of the journal) and otherwise (e.g. results were discussed in The Economist).

As part of the efforts to enhance collaboration between Academia and Industry, the project has organized 5 industrial workshops on the subjects of nanophotonics for photovoltaics and nanophotonics for lighting. A stable series of workshops has been established in collaboration with EU-PVSEC (the main photovoltaics conference in Europe) and ForumLED, and will continue beyond project duration.

The project has produced over 160 papers in SCI-indexed journals, 25% of them as a result of collaborations among several consortium and/or associate members. It is worth noticing that 25% of the papers were published in top-level journals (with impact factor beyond 10). Also, feature articles were published in the general press, local and regional television or even in Braille and audio format. The project has achieved or even exceeded all its measurable, quantitative objectives.

1.2 Project context and objectives

The *Nanophotonics for Energy Efficiency (nanophotonics4energy)* consortium aims to create a network of researchers with excellence in the field of nanophotonics, to focus on innovative ideas for photovoltaic and lighting applications.

Scientists benefit tremendously from networking activities. Conferences and workshops are not only a means to stay abreast of latest developments but provide a stimulating environment for novel ideas. They also give much needed visibility to younger researchers (talent spotting) and facilitate collaborative research by pooling of resources such as research expertise, ideas, funds and research materials. By forming a network, a core group of researchers will create sufficient critical mass to engage with industrial companies for mutual gain. Feedback from industrial stakeholders in turn provides credibility and help focus mid- to long-term research, in terms of societal and economic impact.

The latter is essential if emerging echnologies like nanophotonics are to create a disruptive impact in the energy sector. Nanophotonics has the potential to address current gaps in the market (*e.g.* high costs and low performance) with next-generation technologies. Examples include quantum dots integrated in LEDs for tuning white light generation; multiple exciton generation with inorganic nanocrystals to overcome the theoretical efficiency limit of 31%; photonic crystal enhanced light extraction, by up to 73 %[3] and surface plasmon-enhanced light trapping in Si solar cells at longer wavelengths (up to 16 fold improvements).

Current research, as described here, is mainly at proof-of-concept stage and has yet to make its way to applied research and development. In addition, European nanophotonics research covers a broad spectrum of concepts and technologies and applications in the domains Displays, Sensors and Optical Interconnects, Telecoms, Data Storage as well as Photovoltaics and Lighting.

[3] Wierer et al. III-nitride photonic-crystal light-emitting diodes with high extraction efficiency, Nature Photon vol. 3 (3) pp. 163-169 (2009)

The Global Energy Issue

Despite the best efforts to reduce energy use, world marketed energy consumption is projected to increase by 50 percent from 2005 to 2030.[4] Electricity currently accounts for one third of the global energy consumption – some 15 million GWh - of which 21 % is due to lighting. In homes and offices, lighting makes up to 50% of the buildings total energy consumption. Current energy demands are met by the combustion of fossil fuels, the largest source of CO_2, contributing to the greenhouse gas effect and global warming.

As the scarcity of fossil fuels increases and climate change worsens – it is estimated, that without further action, the global average temperature will increase by 1.8 to 4°C this century[5] – generation and harvesting of electrical energy requires a more intelligent approach.

In 2007, the European (EU) Council endorsed an integrated climate change and energy strategy for minimum 20% cut in emissions by 2020. One of the 3 underpinning objectives set is a **20% reduction in energy consumption through improved energy efficiency**.

The new administration of the United States government has pledged that 10% of electricity will come from renewable sources by 2012, and 25 percent by 2025 and to deploy the cheapest, cleanest, fastest energy source.

Where can savings be made?

Lighting presents a major potential for savings in terms of electricity consumption, by changing to energy efficient alternatives, such as light emitting diodes (LEDs) and organic light emitting diode (OLEDs). It is well known that incandescent light bulbs convert only 10% of energy to light, while fluorescent converts about 25%. The US expects to save 150 M tonnes in carbon emissions – 7% of country's electricity cost – once projected lighting efficiency targets are met.

The European Commission (EC) DG for research aims to "*reinforce research and technological development in new lighting technologies and applications*".[6] With big players such as Philips

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[4] International Energy Outlook 2008, DOE/EIA-0484(2008)

[5] Leading global action to 2020 and beyond, EC (2008)

[6] Addressing the challenge of energy efficiency through Information and Communication Technologies, EU COM (2008)

and Osram, Europe has a very strong business position in this field and through EU projects such as OLED100.eu[7] they will ensure the rapid transfer of results into real products.

The OLED100.eu project, a 12.5M€ investment, is leading the way in OLED technology development for exploitation by the European lighting industry. Targets set by the project include achieving 100 lumens per watt power efficiency on a unit area of $100cm^2$ by 2011.

The photonics portfolio of the ICT work programme funds this and several other solid-state lighting (SSL) and organic photonic research projects. However, until now funding levels are low, especially for SSL, which accounts for 2% of the total ICT photonics budget (€ 223M), while organic photonics accounts for 14%.

Competition in terms of research is strong, especially in the US. The Department of Energy's (DoE) solid-state lighting programme is spearheading R&D efforts to improve energy efficiency and performance of LEDS and OLEDs for general illumination applications. Since this scheme began in 2000, nearly $ 115M has been used to fund over 100 projects, with 71 patents having since been accepted or awarded. The scheme covers core and technological research right through to product development. From a baseline of 25 lm/W in 2002 the target for 2009 is 107 lm/W with the aim to achieve 200 lm/W in a lab device and 160 lm/W in a commercial device by 2025.

Alternative to fossil fuel

The vision of the European Photovoltaic Industry Association (EPIA) is that by 2020, 6 – 12% of European electricity should be generated with Photovoltaic (PV) systems. To achieve this, new developments with respect to material use and consumption, device design, reliability and production technologies, as well as **new concepts to increase overall efficiency are required**.

The main drivers in solar cell technology are reducing cost and increasing efficiency. Crystalline silicon is still the mainstay of the PV industry (90% in 2007) though efficiencies are low (approx. 20%) and shortages of high-purity, low-cost (poly) silicon required for solar cell production are driving new research.[8] Triple junction solar cells are current state of the art

[7] OLED100.EU – FP7 ICT Collaborative Project Sep 2008 – Aug 2011 (www.oled100.eu)

[8] EPIA/Greenpeace Report - Solar Generation V (2008)

(35% efficiency) but applications are limited. Quantum dot-based solar cells can theoretically offer higher conversion efficiencies, as they can be manufactured to absorb any specified wavelength of light.

How can nanophotonics help?

Nanophotonics is an emerging area emanating from optics and photonics that harvest new functions and properties of photon generation and absorption by nanostructures and sub-wavelength phenomena. While it can play a key role in increasing energy efficiency for light harvesting and light generation for solar and lighting technologies, no clear research agenda has yet emerged. European technology platforms such as Photonics21 and Photovoltaic are leading the way from an industrial point of view, along with the European Photovoltaic Industry Association (EPIA) and the European Photonics Industry Consortium (EPIC). However a bottom-up approach is required to ensure that novel ideas and scientific breakthroughs as well as established proof-of-concepts in research institutes and universities are not overlooked by industry and are promoted along the value chain.

We have identified core nanophotonic research in Europe as a disruptive approach to light harvesting and light generation. By providing coherent research lines, this network of excellence aims to establish a mid- to long-term research agenda for eventual take-up by industry.

1.3 Description of the main results

The Nanophotonics for Energy Efficiency Network of Excellence has focused on the promotion of nanophotonics research in energy efficient applications through the consolidation of existing resources and setting up new partnerships. Especial emphasis has been put to enhance information flow and collaborations between academia and industry. The project was structured in 6 different work packages. The main outcomes of each one of them are outlined below.

WP1: Creating a Nanophotonics for Energy Efficiency Forum

Main objectives:

- Durable integration of European researchers in nanophotonics for energy efficiency via a concentration of research centres
- To facilitate access to expertise and state-of-the-art equipment resources and facilities

Although not initially foreseen in the project, an Associate Membership scheme has been put in place in order to involve the research and innovation community in the field at large. The result has been very successful, with a total of 57 associate members at the end of the project, 53 of them actively participating in project activities. 18 (i.e. over 30%) of the associate members are industrial.

Besides this community of 66 institutions with a tight information flow and collaboration channels, a broader community has been formed through existing social/professional networks. The project has communication and discussion channels in LinkedIn, Twitter and Facebook, each one of them with more than 200 participants. Besides that, the project web page http://n4e.eu/ is used by over 400 unique users per month and includes a repository of all the public information generated in the project, an overview of the facilities available within the consortium and clear information on how to initiate collaborations.

The research exchange program, which was established in the second year of the project has seen a steady increase in the number of exchanges over the project duration, with a total of 32 exchanges carried out throughout the project.

We have set up an eLab pilot experience at the University of Southampton, setting the foundations for a distributed nanofabrication and characterization laboratory consolidating facilities essential for undertaking research in the context of N4E. We have setup and tested remote access both within the Consortium and with external partners.

A Memorandum of Understanding has been signed by all Consortium members for continued collaboration beyond the project duration.

WP2: Academia-Industry Forum

Main objectives:

- To carry out a scientific & technological assessment of nanophotonics knowledge-base for energy efficiency;
- To evaluate the impact of nanophotonics in Lighting and PVs; and
- To promote the interaction between research and industry in the network

The project has organised a total of 5 industrial workshops. A first industrial workshop was organised at the MINATEC campus in Grenoble in November 2012, followed by another workshop at KTY in Stockholm in November 2013. The following events were co-located with major conferences that have a significant number of attendees from industry: EU-PVSEC for photovoltaics and ForumLED for lighting.

The Workshop "Nanophotonics: Essential ingredient for efficient and cost-effective solar cells?" was organised on October 2013 within the EU PVSEC2013 conference in Paris. All the information related to the event, including handouts from all talks is available at the project website: http://n4e.eu/index.php/news-a-events/network-events/222-nanophotonics-pvworkshop2013-execsumm. This event was co-organised with the Nanophotonics Europe Association and supported by Photonics21 and EPIC. The success of the event prompted for a follow-up event at EU PVSEC 2014 in Amsterdam: the workshop "Nanophotonics: From Research to Driving Competitiveness in Solar Cells" which took place in September 2014. Detailed information about the event can be found at http://n4e.eu/index.php/news-a-events/network-events/233-eupvsec2014.

A similar event, but focused on lighting technologies was organised during ForumLED 2014 in Paris in October 2014: "Nanophotonics – Increasing efficiency and cost-effectiveness in solid-state lighting". Information about the event is available at http://n4e.eu/index.php/news-a-events/network-events/234-forumled2014

The success of these events has led to establishing stable nanophotonics workshops both at EU PVSEC and ForumLED with a 2-yearly periodicity.

The project has carried out a science and technology watch on nanophotonics for photovoltaics and lighting and generated a yearly summary of the main results, publicly available on the project website.

WP3: Light Harvesting and Light Generation

Main objectives:

- To establish a cooperative framework within which the possibilities of nanophotonics for improving efficiency of light harvesting
- To establish a cooperative framework to address the improvement in efficiency of light generation employing nanophotonics
- To establish a seed project scheme within which the cooperative frameworks will be efficiently meshed and further developed

This work package is aimed at the organization of research topics and working groups to perform joint research activities addressing disruptive nanophotonics approaches to efficient harvesting of light, in particular for photovoltaic/solar cell applications and/or efficient light generation, in particular for solid state lightning systems.

At the end of year 1, N4E partners assessed the research carried out within the consortium. Based on this (reported in deliverable reports D3.1, D3.2, D3.3 and D3.4) and together with the inputs from the science and technology analysis in WP2 and the inputs from the Industrial Advisory Board, the key research topics were started to be explored in the Framework of Seed Project Scheme (Task 3.3). These Seed Projects (SPs) are meant to explore highly competitive ideas among partners (or associates) and are evaluated by an external scientific committee with strict criteria. Focusing on novelty and impact beyond the state of the art (SoA), integration and (reasonable) feasibility, and apart from obvious scientific goals, these SPs aim to initiate (or consolidate) active collaboration among institutions working on improving energy efficiency with nanophotonics and to establish the basis for future European calls. SP calls provide funding for short-term (maximum 6 months) and selected SPs must address ideas, methods or devices to increase energy efficiency through the use of disruptive nanophotonics approaches.

The proposal evaluation methodology was discussed both within the Consortium and with the Advisory Board and Project Evaluators. In more detail, the evaluation criteria include the following aspects:

- Relevance to NoE goals and research strategy
- Cutting-edge idea
- Potential progress beyond the SoA
- Feasibility of the idea (schedule, existing facilities, previous work, realistic budget)
- Impact

In order for a proposal to be eligible for funding it must include a minimum of two different partners. Institutions outside the N4E Consortium are also eligible for participation but jointly with at least one Consortium member.

A total of 7 calls for Seed Project Proposals have been published in the project. 65 proposals were submitted for evaluation and 29 were selected for funding. A total of 42 different institutions, including the 9 Consortium members and 14 industrial institutions have participated in proposals.

All projects have been finalised and reports have been generated (publishable summaries of the results obtained in all the funded projects are available on the http://n4e.eu/ web page. Besides that, an analysis of the impacts of each of the previous seed projects has been carried out and included in a Deliverable report. In addition to the result summary reports, an analysis has been carried out of the impacts generated by the seed projects from all calls and was included in a deliverable report. This analysis shows that some of the seed projects have resulted in top-level publications (e.g. the most cited paper in 2011 in the prestigious Nano Letters journal, or several papers selected for the cover page of journals like Advanced functional materials). Also, seed project results have been discussed in general publications like "The Economist".

WP4: Education and Training

Main objectives:

- To train the next generation of scientists and engineers in emerging nanophotonics and applications for energy efficiency.
- To establish good practice in the training of early-stage and experienced researchers in energy relevant

The principal aims of this work package were on the one hand to train the next generation of scientists and engineers in emerging nanophotonics to foresee novel applications for energy efficiency and on the other hand to establish good practice in the training of early-stage and experienced researchers. To this end, promotional and lecture material for nanophotonic topics related to energy on various levels have been made available. Lectures, as prepared by network members have been collected. Also specific topical schools have been organized for direct interaction with the students, of which the lecture material are available. Special attention has also been paid to improving skills as important as communication, technical writing and project management. Lecture or presentation material have being collated and made publicly available on project website or virtual network. These schools' main objective is to give the opportunity to young researchers to share their research results and at the same time to use the expertise available within the network to develop their scientific/technological skills on their respective research lines.

Throughout the duration of the project, the project has (co)organised 6 schools, there have been 18 lectures in international courses, and the Consortium has produced 80 MSc theses and 32 PhD theses in subjects directly related to the activities of the Network of Excellence. Specific training has been devoted to important areas like scientific communication, intellectual property rights, or networking. Also, 2 workshops with hands-on clean-room processing training took place (at the UPC in Barcelona and the University of Southampton).

WP5: Dissemination

Main objectives:

- To spread recent results of NoE research work among academia and industry for wide-scale dissemination.

- To create public awareness of research developments and their potential uses.
- To facilitate information exchange between the participants of NoE and other scientists and to encourage the commercial utilization of the project results.
- To support interactions between the communities of the EU and other countries.
- To make contribution to establishing a European Photonics community.

Significant efforts have been devoted to dissemination of project results and nanophotonics for energy efficiency in general to the scientific community, industry, and the public in general. One of the pillars of the dissemination activities has been the close collaborations with existing institutions like Photonics21, the European Optical Society, IEEE Photonics Society, Nanophotonics Europe Association or EPIC.

Regarding dissemination to industry and as reported above, we have carried out several workshops with a clear industrial focus. Regarding the public in general, several network members have published feature articles in the daily press on topics related to nanophotonics for energy efficiency, and several events have been organised for primary and secondary school students.

The scientific output of the project includes a total of 163 SCI-indexed publications (all of them explicitly acknowledging the project), with an outstanding number of high quality outputs: 25% of them have an impact index higher than 10. Also, it is worth mentioning that 25% of the publications are the result of collaborative research, with authors form at least 2 Consortium members or Associate members.

Among the 163 publications, we present here a selection of some of the most outstanding publications originating from the project:

- F. H. L. Koppens, D. E. Chang, and F. J. G. de Abajo, "Graphene Plasmonics: A Platform for Strong Light–Matter Interactions" Nano Letters, 11, 3370 (2011)[9]
- H. Savin, P. Repo, G. von Gastrow, P. Ortega, E. Calle, M. Garin, R. Alcubilla, "Black silicon solar cells with interdigitated back-contacts achieve 22.1% efficiency " Nature Nanotechnology, in press (2015)

[9] Outcome of the GLH seed project from Call 1. Most cited paper in 2011 Nano Letters journal.

- Dev, B. Dev Choudhury, A. Abedin and S. Anand, "Fabrication of Periodic Nanostructure Assemblies by Interfacial Energy Driven Colloidal Lithography" Advanced Functional Materials, 24, 4577 (2014)[10]
- V. Dhaka, J. Oksanen, H. Jiang, T. Haggren, A. Nykänen, R. Sanatinia, J.-P. Kakko, T. Huhtio, M.Mattila, J. Ruokolainen, S. Anand, E. Kauppinen, and H. Lipsanen, "Aluminum-Induced Photoluminescence Red Shifts in Core-Shell GaAs/AlxGa1-xAs Nanowires" Nano Letters, 13, 3581 (2013)[11]
- S Naureen, N Shahid, A Dev and S Anand, "Generation of substrate-free III-V nanodisks from user-defined multilayer nanopillar arrays for integration on Si" Nanotechnology 24 225301 (2013)[12]
- M. Acebron, J.F. Galisteo-Lopez, D. Granados, J. López-Ogalla, J.M. Gallego, R. Otero, C. Lopez, and B. H. Juárez, "Protective Ligand Shells for Luminescent SiO2-Coated Alloyed Semiconductor Nanocrystals" ACS Applied Materials & Interfaces, in press (2015)[13]
- A. Espinha, M. C. Serrano, Á. Blanco and C. López, "Thermoresponsive Shape-Memory Photonic Nanostructures" Advanced Optical Materials, 2, 516 (2014)[14]
- F. Gallego-Gómez, A. Blanco and C. López, "Exploration and Exploitation of Water in Colloidal Crystals" Advanced Materials, in press (2015)[15]
- M. Adam, Z. Wang, A. Dubavik, G. M. Stachowski, C.Meerbach, Z.Soran-Erdem, C. Rengers, H. V. Demir, N.Gaponik, A. Eychmüller, "Liquid-Liquid Diffusion Assisted Crystallization (LLDC): a Fast and Versatile Approach towards High Quality Mixed Quantum Dot-Salt Crystals" Advanced Functional Materials, in press (2015)[16]

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[10] Selected as cover page for the journal issue

[11] Related to seed project SORINS, collaboration with Associate Member Aalto

[12] Selected as cover page for the journal issue

[13] Related to seed project BE-LED, collaboration with Associate Members IMDEA and ACREO AB.

[14] Selected as cover page for the journal issue

[15] Selected as cover page for the journal issue

[16] Related to seed project Macrocrys-QD. Selected as cover page for the journal issue. Collaboration between Bilkent and TUD

- T. Otto, M. Mueller, P. Mundra, V. Lesnyak, H. V. Demir, N. Gaponik and A. Eychmuller "Colloidal Nanocrystals Embedded in Macrocrystals: Robustness, Photostability, and Color Purity," Nano Letters, 12, 5348 (2012)[17]
- X. Zhang, C. A. Marocico, M. Lunz, V. A. Gerard, Y. K. Gun'ko, V. Lesnyak, N. Gaponik, A. S. Susha, A. L. Rogach and A. L. Bradley, "Experimental and Theoretical Investigation of the Distance Dependence of Localized Surface Plasmon Coupled Forster Resonance Energy Transfer" ACS Nano, 8, 1273 (2014)[18]
- E. Mutlugun, P. L. Hernandez-Martinez, C. Eroglu, Y. Coskun, T. Erdem, V. K Sharma, E. Unal, S. K. Panda, S. G. Hickey, N. Gaponik, A. Eychmuller and H. V. Demir, "Large-area (over 50 cm × 50 cm) freestanding films of colloidal InP/ZnS quantum dots," Nano Letters, 12, 3986 (2012)[19]
- H. V. Demir, S. Nizamoğlu, T. Erdem, E. Mutlugun, N. Gaponik, A. Eychmuller "Quantum dot integrated LEDs using photonic and excitonic color conversion," NanoToday, 6, 632 (2011)[20]
- B. Guzelturk, Y. Kelestemur, K. Gungor, A. Yeltik, M. Z. Akgul, Y. Wang, R. Chen, C. Dang, H. Sun and H. V. Demir, "Stable and Low-Threshold Optical Gain in CdSe/CdS Quantum Dots: An All-Colloidal Frequency Up-Converted Laser" Advanced Materials, in press (2015)[21]
- F. Riboli, N. Caselli, S. Vignolini, F. Intonti, K. Vynck, P. Barthelemy, A. Gerardino, L. Balet, L. H. Li, A. Fiore, M. Gurioli and D. S. Wiersma, "Engineering of light confinement in strongly scattering disordered media" Nature Materials, 13, 720 (2014)[22]

Besides publishing scientific results, the members of the Consortium also have an active policy of protecting intellectual property, so that it can be exploited and can thus contribute to increasing European competitiveness and job creation. Consortium members have generated a total of 21 patents on topics directly related to the project.

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[17] Paper that resulted in the bilateral BMBF-Tubitak project and two new seed projects. Collaboration between Bilkent and TUD

[18] Collaboration between TUD and Associate Members City University of Hong Kong and Istituto Italiano de Tecnologia

[19] Collaboration between TUD and Bilkent

[20] Collaboration between TUD and Bilkent

[21] Selected as cover page for the journal issue

[22] Collaboration between LENS and Associate Member CNR

1.4 Expected final result and their potential impact and use

Although the specific impacts of a Network of Excellence are difficult to quantify, this 5-year project has established a solid network of collaboration that spans a total of 66 different institutions. Some of the events organised, like e.g. the EU-PVSEC Workshops on Nanophotonics, are considered of top quality and have attracted some of the most reputable speakers in the field. The event will continue beyond the project duration with a 2-yearly periodicity. Ideas and collaborations from the Network have been the seed for a good number of new results, awards and projects, as outlined in deliverable D5.7. Some examples are the participation of Consortium members in the Graphene Flagship (on activities directly related to light harvesting at the nanoscale, originally investigated on a Seed Project), the creation of a StartUp company (on perovskite-based solar cells) by a former N4E student, the 5 Consortium students being awarded the Photonics21 Student Innovation Award for work carried out within the project, or a great number of European and National projects being funded whose initial ideas were validated on a Seed Project.

The project has achieved and even exceeded all its measurable objectives (see table below). It is important to keep in mind, however, that the outputs of the project will continue to grow even beyond the end of the project and thus the final impact will actually be larger than what can be seen at this moment.

Measurable targets	**Target**	**Actual**
SCI-indexed publications	**40**	**163**
Publications co-authored by several Consortium or Associate members	**40**	**40**
Publications with impact factor >10	**10**	**40**
Companies participating in Seed Projects	**8**	**12**
Universities or Research Centers outside Consortium participating in Seed Projects	**10**	**24**
Patents	**4**	**21**
Additional collaborative projects seeded by N4E	**4**	**>10**
Industrial workshops organised	**1**	**5**

The project has also implemented a durable integration scheme so that the work carried out so far will outlive the project itself. The N4E Durable Integration and Exploitation plan is based on 3 main pillars:

- **Policy**: Providing consolidated inputs to the main actors relevant to the Nanophotonics for Energy Efficiency subject is a key element in ensuring a durable viability of the actions. The role of the Nanophotonics Europe Association (NEA), which most institutions in the N4E Consortium are members of, has been fundamental in increasing the visibility of Nanophotonics at the European level. This has been achieved through the preparation of strategy documents and the communication of the most relevant messages to the Photonics21 platform, the European Photovoltaics Technology Platform and National Funding Agencies. As a result, Nanophotonics is now clearly identified in the key strategy documents at European level. We have been made aware that the Nanophotonics Europe Association documents are also being used for the National Photonics Initiative that is taking place in the US.

  The N4E plans to continue providing consolidated inputs to the NEA, so that the most relevant elements to energy efficiency through the use of nanophotonics are included in future policy documents. This activity, which is taking place continuously throughout the N4E project, will continue beyond project duration.

- **Science and Technology**: The promotion and consolidation of high-quality science and technology is one of the key objectives of the N4E Network of Excellence, as specified in the Description of Work. The N4E project has deployed a great number of efforts and resources to achieve this, including plenary meetings, technology workshops, research exchange programs, and the seed project scheme, amongst other. In order to involve the community at large and become a "hub" of activities related to nanophotonics for Energy Efficiency, the Consortium has made significant enhancements to the activities deployed, well beyond the contractual requirements stipulated in the original Annex 1 to the Contract (DoW).

  In particular, an Associate Membership scheme has been put in place, which allows any relevant stakeholder involved in the field of nanophotonics for energy efficiency to get first-hand information about the network activities, participate in the research exchange program and also in the Seed Project scheme. This has proven to be an excellent tool to make the Network's activities known to the community and also to build trust with external players, which will be instrumental in ensuring stable activities beyond the end of project funding.

Significant efforts have also been devoted to the organization of Industry-Academia Workshops, which were not originally foreseen in the project. The first event of this type, was organized in Y3 in Grenoble and a second one in Y4 in Stockholm. Moreover, a specific Workshop to initiate an active collaboration with the European Photovoltaics Technology Platform was organized in Y4 and in Y5 a follow-up workshop on photovoltaics and a first event for the SSL community in Y5 has been organized within the project.

An important outcome of the Workshop with the Photovoltaics Technology Platform was their compromise to involve experts from the nanophotonics community to the relevant topical working groups that are planned in the new organization of the Technology Platform. Moreover, similar events will be organized with a 2-yearly periodicity both at EU-PVSEC (photovoltaics) and ForumLED (lighting).

- **Virtual Lab**: Another key objective of the project is to consolidate resources and expertise in the field of nanophotonics for energy efficiency. To this end, we have continuously improved the database of resources available in the consortium and its visibility in the web. During Year 5 we have set up an eLab pilot experience at the University of Southampton, setting the foundations for a distributed nanofabrication and characterization laboratory consolidating facilities essential for undertaking research in the context of N4E. We have setup and tested remote access both within the Consortium and with external partners. Motivations for the development of a distributed laboratory are:

    - Sharing heavy and expensive instruments and equipment between institutions
    - anytime and anywhere lab access
    - porting lab activity
    - resorting to real systems for illustrations in scientific and outreach demonstrations

A remote laboratory (eLab) is typically a transfer of classical in-situ laboratory towards distance experimentation, demonstration and learning environments. In this pilot we have expanded accessibility to eLab providing a real time interface for the acquisition of data and control of instrumentation

The 3 pillars outlined above can be sustained beyond project duration, even after the funding of the project is finished. The Science & Technology and Virtual Lab activities have particularly benefited from the project extension into Y5, which have allowed us to strengthen their base by providing funding for an additional Plenary Meeting with Associate Members and an Industry Workshop, the first stable session at the NaNaX Conference, and the setting up of a pilot demonstrator of the eLab concept.

Unfortunately, the lack of additional funding after project end will require to end the Seed Project scheme. This is very unfortunate, as this instrument has proven to be an excellent tool to promote collaborations and to foster the implementation of innovative ideas. The amount of funding necessary to maintain such a mechanism would be rather small compared to other funding initiatives (e.g. the size of a CA/CSA project), and once it is operational it requires very little operational efforts or overheads, while providing excellent outputs.

1.5 Address of the project public website & partners contact details

Public website: http://n4e.eu/

- Prof. Gonçal Badenes (coordinator): ICFO-Fundacio Institut de Ciencies Fotoniques, Barcelona, Spain.
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