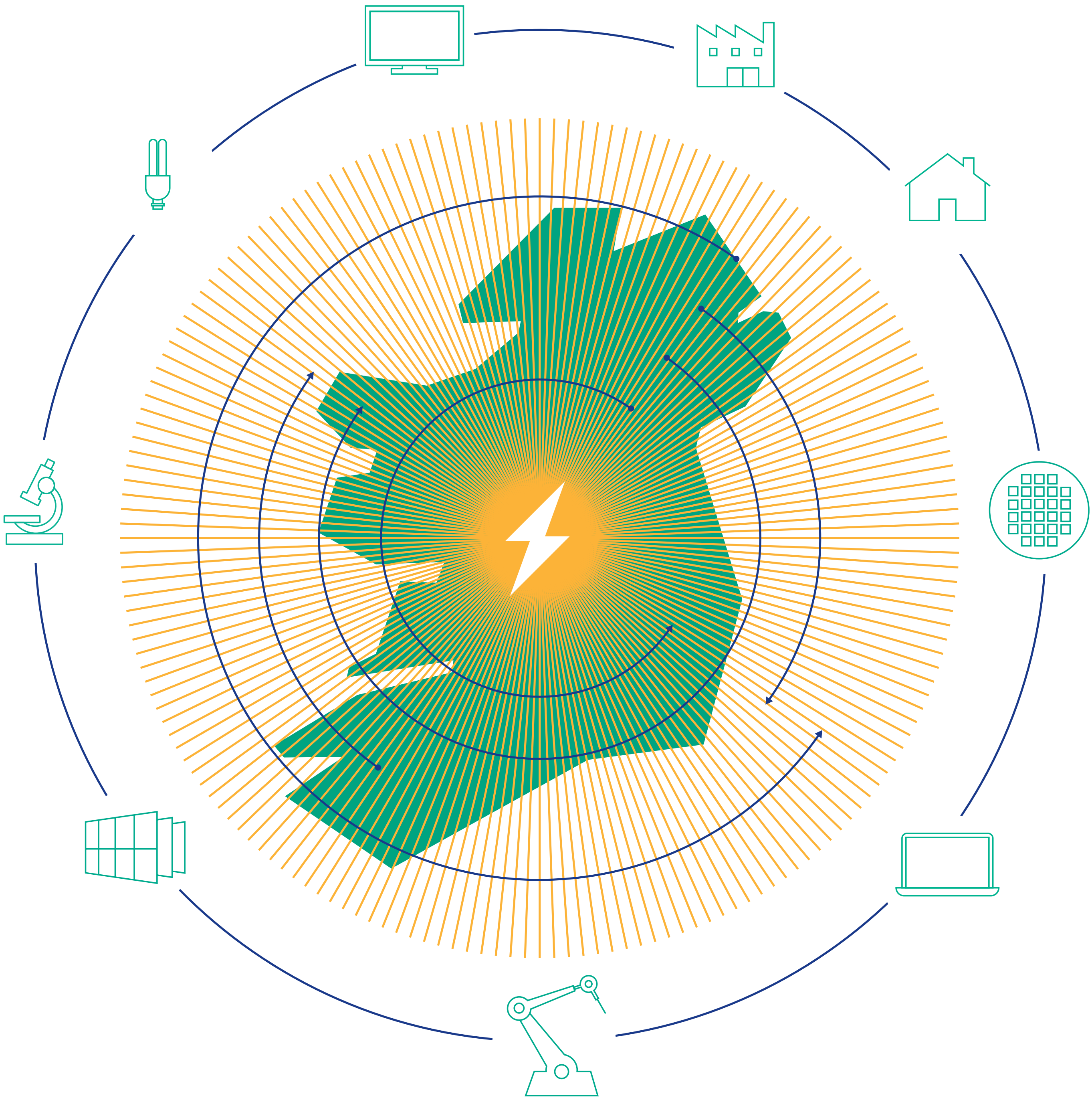
Ireland's Solar Value Chain Opportunity



SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Acknowledgements

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Executive Summary

This report examines in detail the global solar photovoltaic (PV) value chain, Ireland's strengths within it and opportunities for Irish research and industry to capture value and new business from a growing international solar PV market out to 2030.

The study highlights the scope for Ireland to become more than just a 'technology-taker' in the solar PV sector and identifies several priorities to help maximise the role Irish research and industry can play.

The study builds on SEAI's previous report Ireland's Sustainable Energy Supply Chain Opportunity[1] which looked at Ireland's place in the value chains of major sustainable energy products and services.

A Growing Global Market for Solar PV

Solar PV is positioned to become one of the most important energy technologies in meeting global sustainable energy and climate commitments. In the period since 2010 solar PV has been the fastest growing power generation technology worldwide in terms of new capacity additions per year, and projections[2] by the International Energy Agency (IEA) foresee this trend continuing.

Ireland has a small but growing solar PV deployment industry with just over 6MW$_p$ (Megawatt Peak) installed to date, almost entirely on rooftops. Ireland's Energy White Paper[3] recognises an increasing role for solar power in the future Irish energy mix and its contribution will grow, especially as system costs continue to decline. Given the projected scale of the future solar market in Europe and worldwide[4] there is also growing interest from Irish research and industry in the opportunities to capture some of the value of this global market.

The Solar PV Value Chain

The uptake of the technology worldwide has spawned a global industry in the manufacture and deployment of solar PV systems. When considering the opportunities for businesses and researchers arising from the proliferation of a new technology on a global scale it is tempting to fixate on the components and services which form the conventional supply chain – in the case of solar PV: the silicon cells, modules, racking and electronics of which the systems comprise. These are the most visible elements of a technology and typically constitute a large share of the value of the overall market (typically around 70% of the capital investment in a PV system is spread across the supply chains for these products[5]). However these sectors tend to be dominated by a few big players and barriers to entry are often high.

Where the market for a high-value technology is large it can be advantageous to broaden consideration to the 'wider value chain' for the technology which encompasses the whole range of products and services which add value. For solar PV this includes activities such as research and development into new materials, product design and testing, supporting software and controls, maintenance services, and developing other enabling products, e.g. storage technologies. Know-how from sectors where Irish industry and research is strong can potentially be applied in this wider value chain to allow them to capture a portion of a rapidly growing global market. Furthermore, Irish organisations can position themselves to capture a significant share of the domestic solar PV market as it grows and maximise the benefits for Irish businesses, the research sector and communities.

Strengths and Opportunities

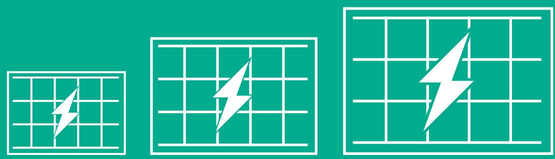
There are several Irish companies and researchers already actively contributing to the solar value chain in areas as diverse as process engineering, control and monitoring, system design and integration, installation and maintenance, battery storage, and materials research. A number of such organisations are featured in case studies in this report, with others identified in the bullets overleaf. Consultation with stakeholders working in solar PV and related sectors helped identify several areas of opportunity for Irish research and industry based on strengths in related sectors and technologies, and considering the position of incumbents and other markets.

1. SEAI, 2014
2. From the hi-Ren Scenario set out in the IEA Solar PV Technology Roadmap (IEA, 2014b)
3. DCENR, 2015
4. IEA, 2014b

5. This is based on a comprehensive literature review conducted as part of this study to quantify how investments in solar developments are shared between the various value centres within the overall solar value chain. See section 3.2.

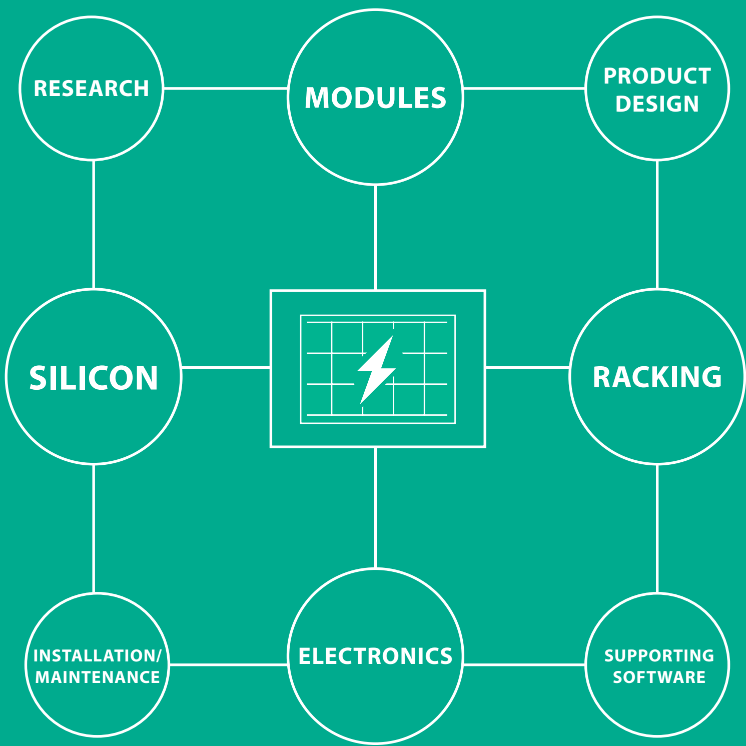
Since 2009 prices for PV modules have fallen by 80%

In the period since 2010 solar PV has been the fastest growing power generation technology worldwide



Just over $6MW_p$ installed in Ireland to date, almost entirely on rooftops

Know-how from sectors where Irish industry and research is strong can potentially be applied in this wider value chain



The opportunities were grouped into three categories:

1. Opportunities to contribute to niche areas of the conventional value chain (i.e. crystalline silicon solar PV on rooftops and in 'solar farms') to reduce costs and improve efficiency. Examples include:

- **Process Engineering:** exploiting Irish know-how in silicon wafer manufacturing to develop technology and IP for optimising manufacturing processes. Companies such as Nines Photovoltaics are innovating in this space and there is strong research/industry collaboration, for example between Intel and the AMBER Research Centre at Trinity College Dublin as well as the Tyndall National Research Institute in Cork.
- **Design & Optimisation:** applying existing expertise in system design, optimisation and integration to develop integrated systems combining PV generation and storage like those developed by Instant Solar or the light-harvesting wireless sensors being developed by Wattz.
- **Installation & Maintenance:** capturing a share of future investments in a growing domestic PV market through the provision of various services in installation and maintenance by Irish businesses.

2. Opportunities to contribute to the development of emerging value chains of innovative new solar PV technologies and applications. Examples include:

- **Building Integrated PV:** designing and fabricating high-value building integrated PV (BIPV) products for glazing, facades and roofing. There is an opportunity to exploit Irish expertise in the building materials sector (in companies such as Kingspan and CRH) as well as research on the integration of PV materials at institutions such as Dublin Institute of Technology.
- **Novel PV Materials:** applying existing Irish research in the development of emerging photovoltaic technologies (e.g. perovskite materials at the AMBER Research Centre, dye-sensitized solar cells at University College Dublin and conjugated polymers at TCD) which can be developed into new applications including powering autonomous devices.
- **Optimising Functional Materials:** applying existing research in the development of other functional materials for PV products other than the photovoltaic component itself. For example, materials for thermal regulation and transparent conducting oxides at institutions such as the Tyndall National Research Institute and Dublin Institute of Technology.
- **Storage & Monitoring:** applying know-how in electrochemistry, e.g. redT and University of Limerick, and monitoring systems to develop off-grid storage products with remote condition monitoring systems.

3. Opportunities to develop and provide supporting services and products which enable further value-add in the wider solar PV value chain. Examples include:

- **Smart Grid Products & Services:** exploiting Irish strengths in ICT systems, data analytics and telecommunications to develop intelligent control, monitoring and communication systems optimised for solar PV and storage. Existing ancillary solutions include the grid automation platform developed by NovoGrid, and the distributed energy storage service offered by Solo Energy.
- **Financial Services:** drawing on experience in Irish financial services companies, already active in the renewable energy market, to develop specialist solutions in areas such as solar PV project financing.

The Size of the Prize

An assessment was made of the potential size of the Irish[6] and EU markets for solar PV out to 2030, based on technically feasible scenarios derived from the IEA's Energy Technology Perspectives analysis[7]. Two scenarios were developed which include two solar PV applications, namely rooftop solar PV (encompassing solar systems installed on the roofs of homes and business), and

6. Note that the scenarios used in this analysis are not forecasts of Irish PV deployment and are not underpinned by any assumption about what policies or measures may be introduced. Rather they are technically feasible scenarios derived from a top-down disaggregation of EU-level projections.

7. IEA, 2014a

ground mount solar PV (larger solar farms connected to the grid or directly to a source of demand). The two scenarios used are based on analysis from the IEA's '6 degree scenario' (6DS) and the 'high renewables scenario' (hi-RenS) which represent futures with low and high ambitions respectively with regards to solar PV deployment in Europe.

The analysis, based on an extensive literature review under this study, determined how investments in solar PV in both scenarios are distributed across the various lifecycle stages of the value chain, e.g. planning and permitting, design, installation and operation. A further level of granularity within each lifecycle stage was explored to determine how these investments are typically spread amongst the products and services within them, e.g. planning and permitting encompasses project management, technical support, financial support, local authority permits and insurance costs. By assessing how the total investment in the Irish and EU solar PV markets will be distributed across the various products and services within the value chain, it is possible to estimate the value proposition for Irish businesses active in these areas.

The table below summarises the outcome of the analysis, presenting a breakdown of the total potential annual expenditure on solar PV in Ireland and the EU in each stage of the technology development[8] lifecycle from research and development through to decommissioning under the two scenarios. This shows that the value of the EU market could reach over €10bn per year by 2030 with the Irish domestic PV market potentially reaching up to €340m per year. It is estimated that over €4.5bn per year of the potential in the EU market is in segments other than manufacturing / materials indicating that an absence of a strong manufacturing sector does not preclude a country from capturing a sizeable share of the market.

Using feedback from stakeholder interviews, estimates were made of how well-positioned Irish business could be in each of the areas of the wider value chain. For each 'value centre,' i.e. component of the wider value chain, an estimate was made for the share of the Irish and European markets that Irish organisations could potentially expect to capture, bearing in mind the influence of incumbents and

The value of the EU market could reach over €10bn per year by 2030.

Table 1: *Breakdown of expenditure in the Irish and EU solar PV markets in 2030 under the two scenarios. The IEA's '6 degree scenario' (6DS) and the 'high renewables scenario' (hi-RenS) represent futures with low and high ambitions respectively with regards to solar PV deployment in Europe.*

Market Size in 2030 (€m/year)	**IRELAND**		**EU**	
Scenario:	6DS	hi-RenS	6DS	hi-RenS
Project Development (Capex)				
Research and development	0.2	1.5	9.6	40.3
Planning & Permitting	3.1	21.2	139	587
Design	1.8	12.2	77.7	314
Manufacturing / materials	31.6	215	1,403	5,915
Installation	6.2	42.7	281	1,208
Quality assurance	0.0	0.1	0.6	1.9
Operation & Maintenance (O&M)				
Operation	7.2	43.3	663	2,267
Decommissioning	0.8	4.7	72.8	249
Total Solar PV Market	**51.0**	**341**	**2,646**	**10,582**

8. Note that this is the value breakdown from the perspective of the developer which explains why Research and Development represents such a small share in this example (developers typically will spent very little on fundamental R&D). The quantitative analysis here did not assess the overall value of RD&D but its potential is elaborated on qualitatively in the report.

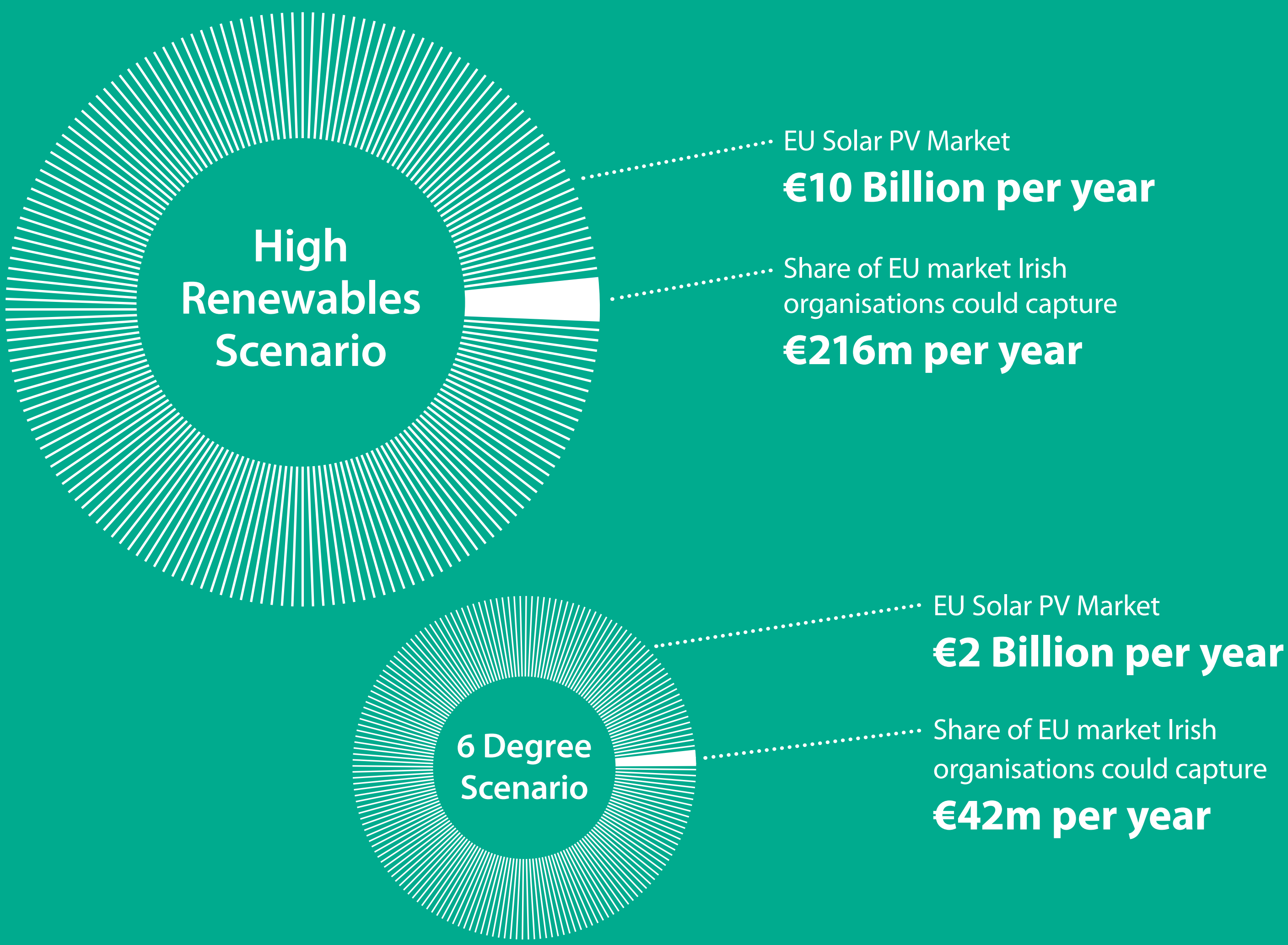
preferences for local suppliers in the EU market. Combining these estimates with the market size estimates set out overleaf gives a sense of the potential size of the prize for Irish businesses if they were to actively pursue relevant opportunities in the solar PV industry in the EU market.

The total potential value that Irish organisations could capture of the EU solar PV market by 2030 under the two uptake scenarios is estimated to be between €42-€216 million per year depending on deployment and the degree to which Irish organisations can engage. The largest segments are ICT and metering, process engineering, energy storage devices, system design and maintenance. It should be stressed that this quantitative analysis only captures the conventional applications, i.e. rooftop and ground mount PV, and doesn't include the potential from other applications and technologies, e.g. BIPV, emerging PV technologies. It also does not quantify the even greater potential in the global market.

Priority Areas

Working with the project stakeholders several priority areas were highlighted where there is both significant value to be captured and Irish research and industry is well-positioned. Four of the most promising areas identified were:

Figure 1: *The potential EU Solar PV market in 2030 and the potential value Irish organisations could capture under two deployment scenarios.*



- **Building Integrated PV:** Stakeholders identified the opportunity to marry Irish strengths in building materials and materials research to design and develop BIPV products and services. Supporting research and demonstration projects focused on integrating PV technology within building materials, such as glazing, facades and roofing products, should be an area of priority for Irish solar research.

- **Materials R&D:** Given the anticipated scale of the global PV market it would be a missed opportunity were Ireland not to apply its world leading materials research to applicable areas of the value chain. This includes research into novel PV materials, such as perovskites, quantum dots and conjugated polymers, other semiconductor materials, nanomaterials and transparent conducting oxides. Research on such materials and their applications in the PV sector should continue to be supported.

- **Process Engineering:** There is potential for Irish research and industry to export expertise in optimising silicon wafer manufacturing. While Ireland does not have a strong manufacturing base compared with other countries, there is scope to develop technology and IP for optimising processing, in what is potentially a very large market.

- **Smart Grid Products & Services:** The analysis suggests that the overall EU market for ICT and metering systems for solar PV could be over €300m per year by 2030. Developing solutions to manage and control the integration of PV and storage in the grid plays to Irish research strengths in ICT, data analytics and telecommunications.

Next Steps

Simply knowing what is possible does not lead to real world impact. There are a range of actions that need to be taken in order for Ireland to play an active role in the global solar PV sector, exporting products and services, and maximising the extent to which Irish business captures the investment in domestic PV systems. Positive steps can be taken by public agencies, the research community and industry to help unlock the opportunities in these priority areas and in others, including:

- Establishing a solar PV forum bringing together industry and research communities on a regular basis could generate opportunities for collaboration and knowledge transfer.

- Targeted support via the SEAI RD&D programme for both fundamental research and projects demonstrating viability in the priority areas identified in this report would represent the most effective use of supports.

- Stakeholders interviewed highlighted non-financial barriers to the development of a domestic solar PV market. A healthy home market could help Irish business to advance their positions within the wider value chain. Some barriers which stakeholders requested are reviewed include planning and grid connection requirements for PV, and development of standards and training for installation.

- Funding and supports for start-ups are available via Enterprise Ireland and the opportunity areas in the PV value chain identified in this study should be recognised as relevant for Ireland. Stakeholders called for greater collaboration between Irish research and industry in developing new enterprises in the solar PV space and both groups should seek out these opportunities and avail of enterprise supports where appropriate.

- Given that solar PV is poised to become one of the most important energy technologies of the 21st Century, there is a need to ensure that Irish citizens have access to good information on the technology to help inform any investment decisions. SEAI will endeavour to provide appropriate updated guidance on the technology for interested stakeholders.

A growing global market

1 Introduction

Solar Photovoltaic (PV) technologies are among the most exciting options for decarbonising the global energy system. The technology has seen a remarkable uptake worldwide in recent years, growing from just 4.5GW_p cumulative capacity in 2005 to over 240GW_p by the end of 2015.[9]

From the period since 2010 solar PV has been the fastest growing power generation technology worldwide in terms of new capacity additions per year. The growth has been largely driven by economic support schemes such as feed-In-tariffs and tax incentives in certain markets. These schemes have facilitated a marked reduction in solar PV system costs achieved through the scale-up of solar module manufacturing and deployment activities, as well as technology and supply chain innovation – since 2009, prices for PV modules have fallen by 80%.[10] The technology is positioned to become one of the most important energy technologies in meeting global climate commitments, with the more ambitious projections[11] by the International Energy Agency foreseeing over 1,700GW_p of total capacity worldwide by 2030.

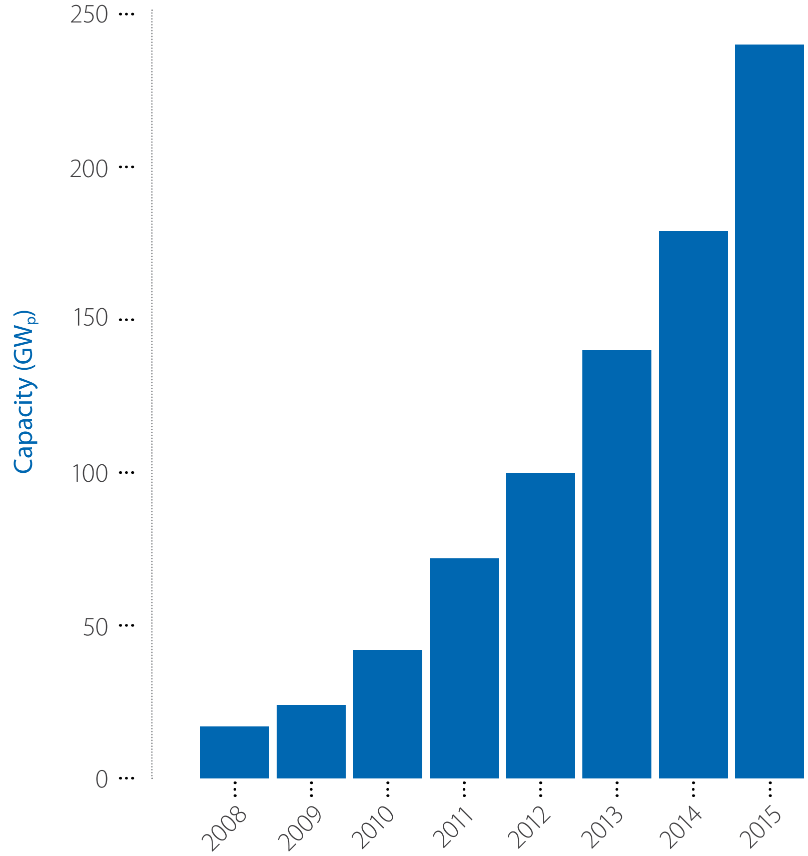
Ireland has a small but growing industry in solar PV deployment with just over 6MW_p installed to date, almost entirely on rooftops. Ireland's Energy White Paper[12] recognises an increasing role for solar power in the future Irish energy mix and its contribution will grow, especially as system costs continue to decline. Given the scale of the future solar market in Europe and worldwide there is also growing interest from Irish research and industry in the opportunities to capture some of the value of this global market. There is potential for Irish know-how in sectors such as materials research, semiconductors, ICT, building materials, and energy storage to add value to solar PV systems deployed across the globe.

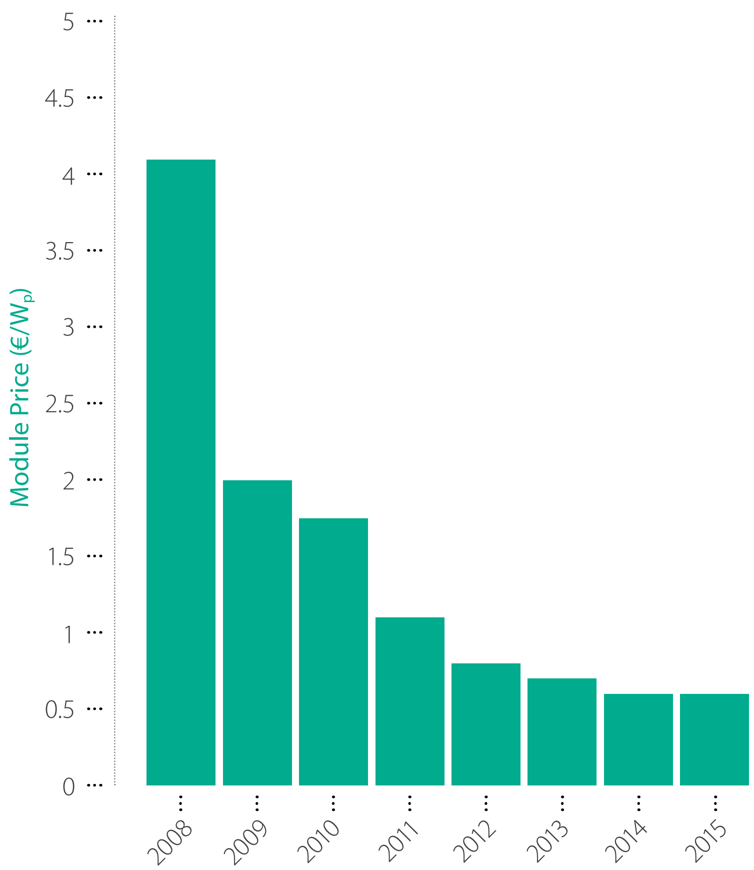
One can consider the wider solar PV 'value chain,' a term which encompasses not just the conventional supply chain, but any products or services which add value to the PV system by improving performance or reducing costs. While the traditional crystalline silicon PV modules will likely continue to be mass-manufactured in China and Taiwan, there are components, services, new materials and new products which innovators in Ireland are well-positioned to contribute and consequently capture a portion of a very large market.

9. IEA-PVPS, 2016
10. IRENA, 2016
11. From the hi-Ren Scenario set out in the IEA Solar PV Technology Roadmap (IEA, 2014b)
12. DCENR, 2015

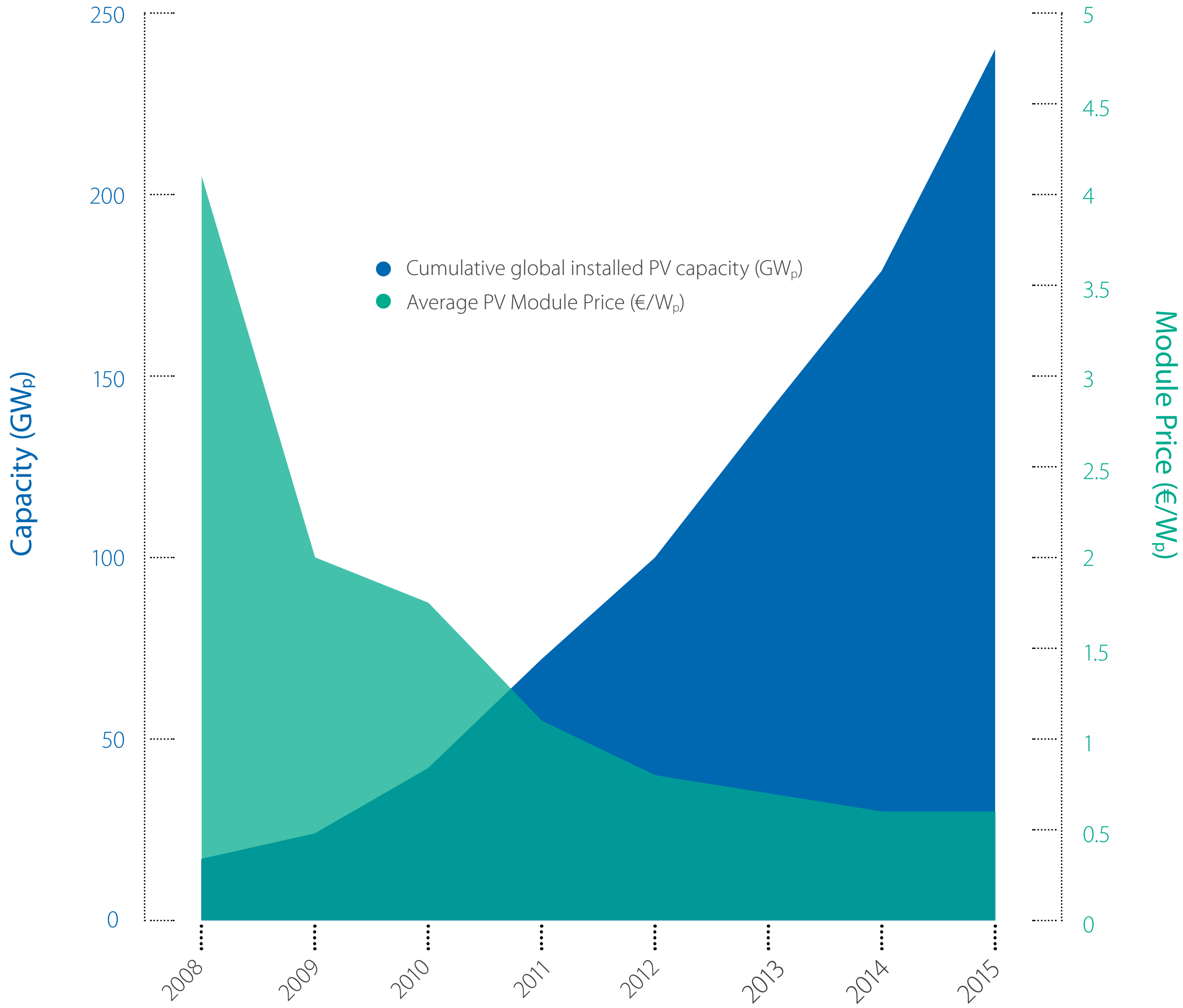
Figure 2: *Cumulative global installed solar PV capacity (GW_p) and average PV module price (€/W_p). Capacity data from Solar Power Europe and Fraunhofer ISE. Module prices are for crystalline silicon in Europe (data from pvXchange).*

Cumulative global installed capacity
2008 - 2015





Average PV module price (€/W_p)
2008 - 2015



This report examines the global solar PV value chain, Ireland's strengths within it and opportunities for Irish research and industry to capture value and new business from a growing international solar PV market. The report is structured as follows:

- *Section 2 sets out the current status of solar PV in Ireland*
- *Section 3 maps out the value chains for the most common solar PV applications*
- *Section 4 identifies Ireland's strengths and opportunities in the PV sector*
- *Section 5 presents scenarios for the Irish and EU market value and to what extent Irish industry can capture this value*
- *Section 6 sets out priorities and next steps for growing Irish involvement in the value chain*

The growing role of solar PV in Ireland

2
Solar PV Status in Ireland

Ireland currently has a small but growing industry in solar PV deployment with just over $6MW_p$ installed as of the end of 2016.[13]

It may not initially seem like an obvious location for the deployment of a technology which relies on plentiful sunlight for optimal operation, but recent improvements in the technology performance and reductions in system cost have made solar PV an increasingly viable option in northern European countries. Throughout Europe there is a growing recognition of the importance of this technology in the renewable energy mix and its potential complementarity with other intermittent renewable energy technologies such as wind and hydropower. Solar PV is recognised as a mature technology which can contribute to meeting Member State renewable energy targets, including those in Ireland.

Solar Photovoltaic Technology

Materials which generate electricity when exposed to light are known as Photovoltaic (PV) materials. The Photovoltaic effect is observed in certain semiconductor materials in which a voltage is created under incident electromagnetic radiation (e.g. visible light) at a particular wavelength. There are a wide variety of solar PV technologies based on different semiconductor materials, the most commonplace to date being those using crystalline silicon as the photovoltaic material. There are also a range of different products and applications, perhaps the best known being the solar panels (modules) being deployed on rooftops and in ground-mounted 'solar farms' at an increasing pace worldwide. The first such solar modules were developed more than 50 years ago and have been mass manufactured for over 25 years. Solar PV technology has seen the fastest growth in deployment of any renewable electricity technology since 2010, reaching over $240GW_p$ installed capacity worldwide by the end of 2015. The most ambitious projections by the International Energy Agency anticipate over $1{,}700GW_p$ of total capacity worldwide by 2030. More information on the various solar PV technologies and applications is provided in section 3.1.

13. Data compiled by SEAI from the National BER Research Tool, historical energy suppliers survey, Electric Ireland domestic scheme and database of non domestic installations.

Domestic Rooftops

The main driver for uptake at present is Part L of the domestic building regulations which covers the conservation of fuel and energy in dwellings. This requires a proportion of the energy consumption (electricity, space heating, hot water) of a dwelling to be provided by renewable energy sources. In the absence of renewable heating the minimum requirement for electricity is 4kWh/m2/year. In many cases the installation of solar PV modules on new homes is the most cost effective means of meeting this requirement. In 2015, for example, almost half of all new houses (i.e. non-apartments) registered on the Building Energy Rating (BER) database included solar PV, with an average array size of 1.2kW_p.

Commercial & Public Sector Rooftops

Larger rooftop arrays are also beginning to appear in Ireland as PV systems become an increasingly worthwhile investment for businesses and public bodies. Several large systems have been installed recently with grant support from SEAI, including a 300kW_p system installed on the headquarters of Kingspan Insulation in Castleblaney, and a 250kW_p array on the roofs of Iverk Produce's cold storage sheds at the O'Shea family farm in Piltown, Co. Kilkenny (see text boxes). As solar PV system costs have come down they are reaching a point where the installation of arrays on commercial rooftops where there is a consistent daytime electricity demand can represent an economically beneficial investment.

Kingspan ESB – PV system design and delivery

In 2015, Kingspan teamed up with the ESB to launch their Funded Solar initiative, an offering developed for businesses across the country as an opportunity to avail of solar energy at no upfront capital cost, allowing clients to take control of their electricity costs and reduce their carbon footprint. Kingspan ESB design, install and maintain the rooftop solar PV system while the electricity used onsite is purchased by the customer at a reduced rate from the grid.

Kingspan ESB has installed the largest PV system in the Republic of Ireland to date, a 300kW_p system on the roof of Kingspan Insulation, Castleblayney. This system was part-funded by SEAI, under its Research, Development and Demonstration (RD&D) programme, as an innovative demonstration project with a bespoke performance monitoring system and a unique financing structure.

Picture Credit: Kingspan ESB

Ground Mount Systems

Interest has also grown in Ireland in the development of larger solar arrays mounted directly on the ground as opposed to on rooftops – such 'ground mount' solar arrays are typically deployed at scales of several MW_p, and often referred to as 'solar farms.' A large number of applications for grid connection and planning have been submitted for such developments in Ireland, with growing interest from a number of solar developers. Ireland now has a dedicated trade association, the Irish Solar Energy Association, promoting ground mount solar as well as rooftop and other PV applications.

Throughout Europe there is a growing recognition of the importance of this technology in the renewable energy mix.

Lightsource Renewable Energy – Solar PV deployment and operation at scale

Lightsource Renewable Energy funds, develops and operates solar PV projects on a global scale. The company has developed and currently operates the largest solar PV asset portfolio in Europe (over 1.7GW operational capacity), with an investment value of over £2.2 billion.

Lightsource most recently developed and connected Northern Ireland's first commercial scale solar PV power station at Crookedstone Road, Co. Antrim. The supply arrangements for this project are innovative in that it is connected directly into Belfast International Airport via a private wire rather than connected to the grid. The project demonstrates the potential for solar power to become a trusted and reliable source of electricity in Northern Ireland. Lightsource currently has a pipeline of viable Irish projects with a total investment value of €300m to be deployed through to 2020.

Picture Credit: Lightsource

2.1
Current Measures Promoting Solar PV in Ireland

Support for and recognition of the technology in Ireland has been demonstrated in a variety of ways to date, including:

- ***Domestic Building Regulations:*** *The energy contribution of a solar PV array may be included in the calculation of the renewable energy contribution within a building to comply with Part L of the Building Regulations for new buildings. Solar PV may, in many cases, represent the least cost option for meeting this renewable energy requirement. Since 2013 almost 4,000 new dwellings recorded in the BER database have included some solar PV generating capacity.*

- ***Accelerated Capital Allowances:*** *Solar PV products meeting the required European and international standards can be registered on the SEAI Triple E Register for accredited energy-efficient equipment. Companies paying corporation tax, sole-traders and non-corporates that purchase listed solar PV products can qualify for a favourable depreciation regime under the Accelerated Capital Allowances scheme, and for VAT refunds when installed for agricultural use by farmers.*

- ***SEAI RD&D Programme:*** *SEAI has committed almost €1m of RD&D funding to solar PV projects since 2005, including an unprecedented €250k in 2015. This includes grants for research as well as demonstration projects. Solar energy was identified as one of the target research areas in the 2016 application guidelines..*

- ***Better Energy Communities:*** *The Better Energy Communities (BEC) programme supports community energy efficiency projects. Over 15,000 homes and hundreds of community, private and public buildings have received energy efficiency upgrades through BEC. The programme has also supported projects to deploy renewable energy technologies such as solar PV within communities. Examples include a 40kW$_p$ PV array in Waterford IT and a 250kW$_p$ system on O'Shea's farm, Kilkenny..*

- ***Building Energy Rating:*** *The Building Energy Rating (BER) of households which install solar PV is given a boost. Microgeneration technologies such as solar PV can increase the dwelling BER if appropriately sized – typically a 2kW$_p$ rooftop PV system will give a boost of around 20 kWh/m2/year. For a typical detached B1 rated dwelling built after 2005 this would raise its BER to an A3. A methodology for the estimation of this is included within the associated Dwellings Energy Assessment Procedure (DEAP) software.*

- ***Home Renovation Incentive:*** *The Home Renovation Incentive (HRI) scheme currently provides for tax relief for Homeowners and Landlords by way of an Income Tax credit at 13.5% of qualifying expenditure on repair, renovation or improvement works carried out on a main home or rental property by qualifying Contractor. Tax relief can be claimed on qualifying expenditure over €4,405 (before VAT at 13.5%) per property. Supply and fitting of solar panels is covered by the scheme.*

- ***Standards Development:*** *SEAI formed a Standards Development Group to develop FETAC micro-generation award standards for installer training courses, including courses for solar PV installers. Final award specifications were provided to FETAC for training awards, which are now FETAC accredited, for two courses (Implementation of micro solar PV systems and Electrical Installation of micro-generators).*

SEAI has committed almost €1m of RD&D funding to solar PV projects.

Better Energy Communities – O'Shea Farm Solar Array

A 2015 project initiated by the Carlow Kilkenny Energy Agency (CKEA) under SEAI's Better Energy Communities (BEC) programme included the installation of a 250kW_p solar array on the roofs of Iverk Produce's cold storage sheds at the O'Shea family farm in Piltown, Co. Kilkenny. Installed by Solar Electric in October 2015, the 1,000 solar panels represented an investment of €270,000, 18% of which was funded by a SEAI grant. The panels will generate over 208,000 kWh of electricity per year, contributing 11% of Iverk Produce's total electricity consumption. This helps provide them with greater energy price certainty and contributes to their overall corporate social responsibility goals, as well as supporting Bord Bia's objectives to reduce energy use in the food supply chain.

Picture Credit: Solar Electric

The distribution of investments in solar PV across the value chain

3 Mapping the Solar PV 'Wider Value Chain'

When considering the opportunities for businesses and researchers arising from the proliferation of a new technology on a global scale it is tempting to fixate on the components and services which form the conventional supply chain – in the case of solar PV: the silicon, modules, mounting equipment, and electronics of which the systems comprise.

These are the most visible elements of a technology and typically constitute a large share of the value of the overall market, but their provision tends to be dominated by a few big players and barriers to entry are often high.

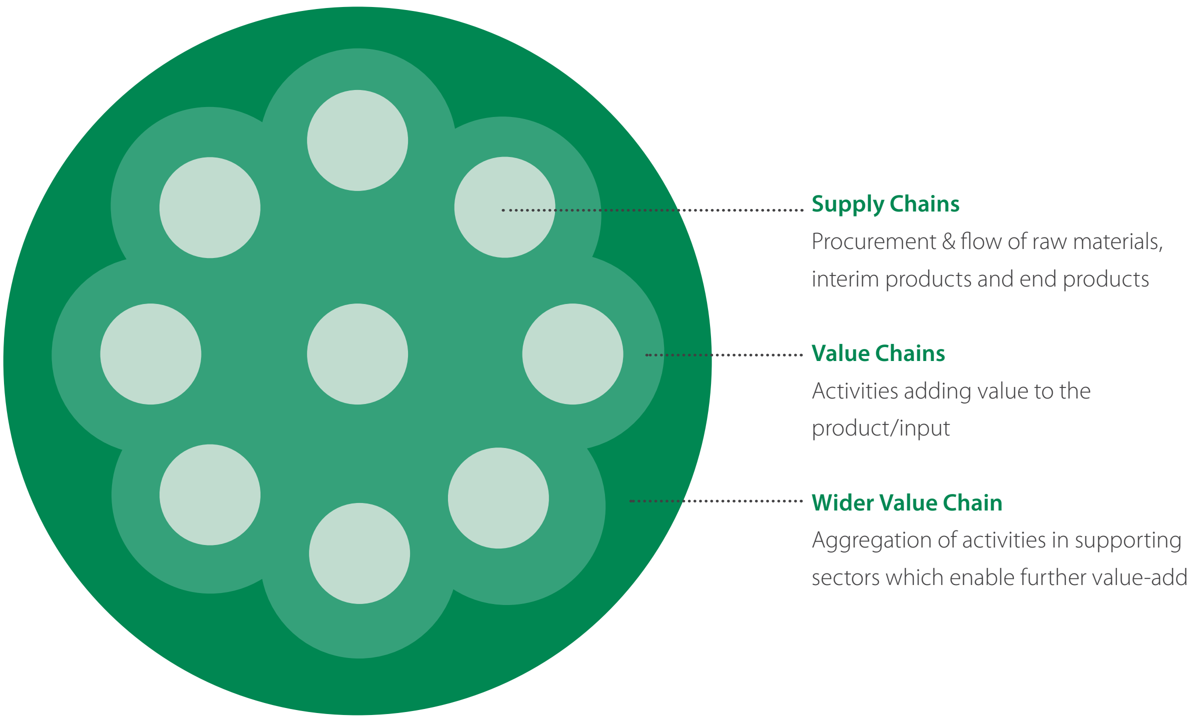
Where the market for a high-value technology is large it can be advantageous to broaden consideration to the 'value chain' for the technology – the range of services and products that add value to a product, including activities such as research and development, product design and testing, and project management. One can further consider the 'wider value chain', encompassing a range of activities and products in supporting sectors which enable further value-add, such as accompanying software and hardware, maintenance services and research into new materials.

This report is concerned with the wider value chain for solar PV and the place of Irish business and research within it. Irish firms have the potential to occupy niches in the wider value chain that may seem like less significant aspects of the PV market, but when export potential to a global market is considered it can scale to represent significant business opportunities. The quantitative element of this report examines the solar PV 'wider value chain' from the perspective of the developer or owner of a solar PV system, exploring how the investment made in the development, operation and maintenance of a rooftop or ground mount system flows through the various parts of the value chain. The analysis is extended to encompass supporting/enabling activities which stand to benefit from the burgeoning global solar PV sector such as electricity storage technologies and R&D into new functional materials. This analysis does not encompass every component of the 'wider value chain' for solar PV, but is limited to those which are directly impacted by the investments made by the developer.

This section maps out all of the component parts (referred to here as 'value centres') of the rooftop and ground mount solar value chains. It then identifies how investment in solar PV systems is distributed between these value centres, in order to subsequently determine the scale of the opportunity for Irish industry and research within each of these areas.

The Wider Value Chain Opportunity

When the demand for a technology becomes sufficiently high it can spawn demand for supporting products and services which can further improve the technology's performance or drive down costs. This report is concerned with the 'wider value chain' for solar PV, encompassing a range of activities and products in supporting sectors which enable further uptake of the technology. To illustrate this one can imagine the individual supply chains of all the products which comprise a solar farm (e.g. solar modules, mounting, power electronics etc.) represented as the lightest green circles in the image below. Surrounding these supply chains are individual 'value chains' in medium green, representing the activities of the companies within the supply chains which add value to the products. We can imagine a larger dark green circle encompassing all of this which represents the 'wider value chain,' an aggregation of activities in supporting sectors which enable further value-add. The wider value chain constitutes an enormous market in which there is scope for lots of smaller players to contribute, above and beyond the small number of big players who dominate the conventional supply chains. For simplicity the 'wider value chain' is simply referred to in this report as the 'solar value chain,' encompassing all of the separate value chains of individual components and services.



3.1 Value Distribution Assessment

A definitive breakdown of how the value of an investment in a solar PV development is distributed across all components ('value centres') of the wider value chain does not exist since costs will vary depending on system size, design, technology, location and operation. For the purposes of this analysis two solar PV archetypes have been selected capturing the most typical installations:

1. **Rooftop: A grid-connected, rooftop crystalline silicon array sized between 1-50kW$_p$.**

2. **Ground Mount: A grid-connected, ground mounted crystalline silicon array sized between 5-10MW$_p$.**

These two archetypes cover a large share of the capacity expected to be deployed in the European and Irish markets. A distinction is often made between the domestic and commercial rooftop markets, but for simplicity in this report a generic 'rooftop' solar value chain[14] is considered, taking an average of the typical system sizes for domestic and commercial installations. Likewise, ground mount PV arrays sized at <5MW$_p$ and >10MW$_p$ are commonplace across Europe, but the above archetype is chosen to represent a typical installation.

There are a wide range of other solar PV applications at a variety of scales including building integrated photovoltaics (BIPV), remote solar PV, concentrated solar PV and floating solar PV arrays. There are also a variety of other photovoltaic materials such as thin-film technologies like Cadmium Telluride (CdTe) and emerging novel materials such as dye-sensitised solar cells (DSSC) and perovskite solar cells. Many of these applications and technologies show tremendous promise but their future market share is impossible to determine. Therefore these applications and technologies have been considered qualitatively in this report (see section 4) while the market value analysis (section 5.2) focuses on the 'conventional' crystalline silicon modules in these two most common applications.

A comprehensive literature review was conducted[15] to quantify how investments in solar developments are shared between the various value centres within the overall value chain. A range of sources classifying and quantifying the value chain were assessed, focusing on EU studies compiling cost data from developers and manufacturer.[16] The literature review and subsequent consultation with stakeholders from the Irish solar industry led to a mapping of the rooftop and ground mount value chains (from the perspective of the owner/developer) classified into eight different 'lifecycle stages' of the project and technology:

1. Research & Development
2. Planning
3. Project Design
4. Manufacturing
5. Installation
6. Quality Assurance
7. Operation
8. Decommissioning

Beneath these major headings, a more detailed cost breakdown structure was used to capture the costs associated with key products, services, and components involved at each stage of the lifecycle – these components are referred to here as 'value centres.' This cost structure was adjusted in light of data availability, with some value centres being combined or eliminated, and others being sub-divided where more detailed cost data was available. Aggregating all of the cost data allowed for the following estimates to be made for each value centre:

- For all Operation and Maintenance (O&M) value centres, a percentage share of the annual project operating and maintenance costs

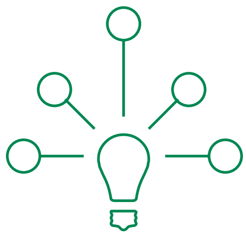
- For all other value centres, a percentage share of the total project capital costs

14. For simplicity the 'wider value chain' is simply referred to here as the 'solar value chain'.
15. The value chain modelling in sections 3-5 was conducted by Ricardo Energy & Environment
16. A summary of the main sources reviewed and applied to the analysis is provided in Appendix B

3.2
Wider Value Chain Maps

The solar PV value chain maps for rooftop and ground mount applications are presented in Figure 4 and Figure 5 respectively. The average percentage of capital costs or annual O&M costs incurred in each value centre of the chain is overlaid on the map. The charts opposite summarise the typical average breakdown by lifecycle stage for each archetype

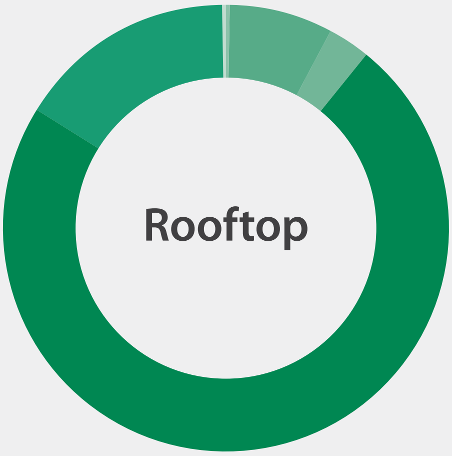
The breakdown opposite demonstrates that the majority of the capital spending on solar developments is used to finance the manufacturing of the relevant hardware. Note again that this is the value breakdown from the perspective of the developer which explains why Research and Development represents such a small share in this example. Developers typically will spent very little on fundamental R&D. In this example the R&D lifecycle stage represents any spending by developers on exploring options with new technologies and thus constitutes only a small part of the wider value chain from their perspective. Note that spending on R&D in solar PV comes from other sources (including public money and investments made by technology developers) which aren't captured here. Furthermore, successfully translating R&D in new PV technologies and applications can open up entirely new markets, the value of which are not quantified here. Therefore the opportunities for value to be captured in the commercialisation of R&D are not fully captured in these charts.



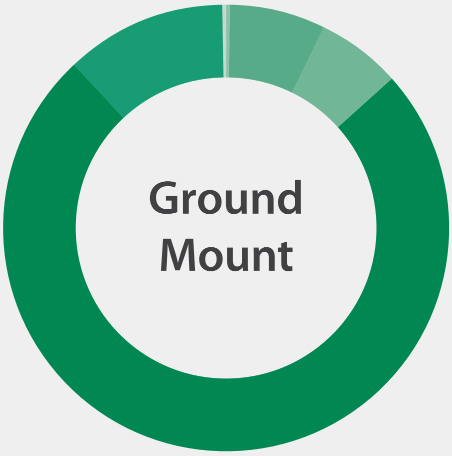
Successfully translating R&D in new PV technologies and applications can open up entire new markets.

Figure 3: Average percentage of cost by lifecycle stage.

Project Development (Capex)

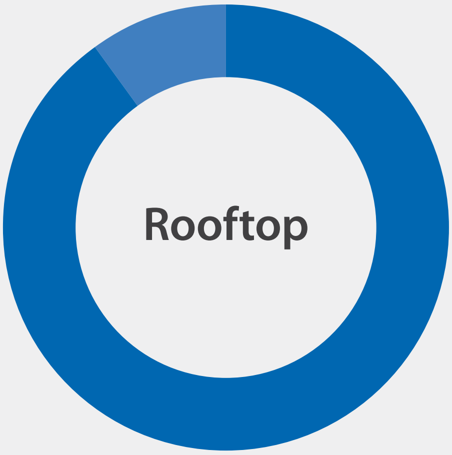


0.5% Research & Development
7.4% Planning
3.2% Design
72.9% Manufacturing
16.0% Installation
<0.1% Quality Assurance

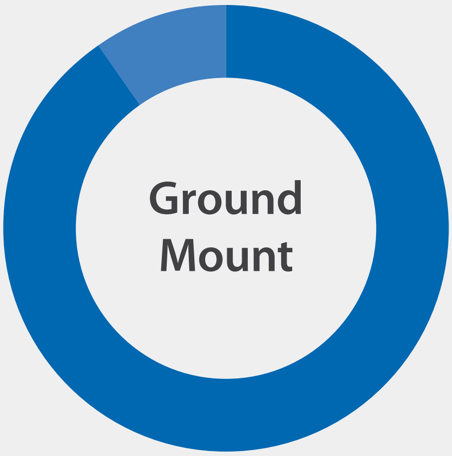


0.5% Research & Development
6.9% Planning
6.1% Design
74.7% Manufacturing
11.7% Installation
<0.1% Quality Assurance

Operation & Maintenance (O & M)



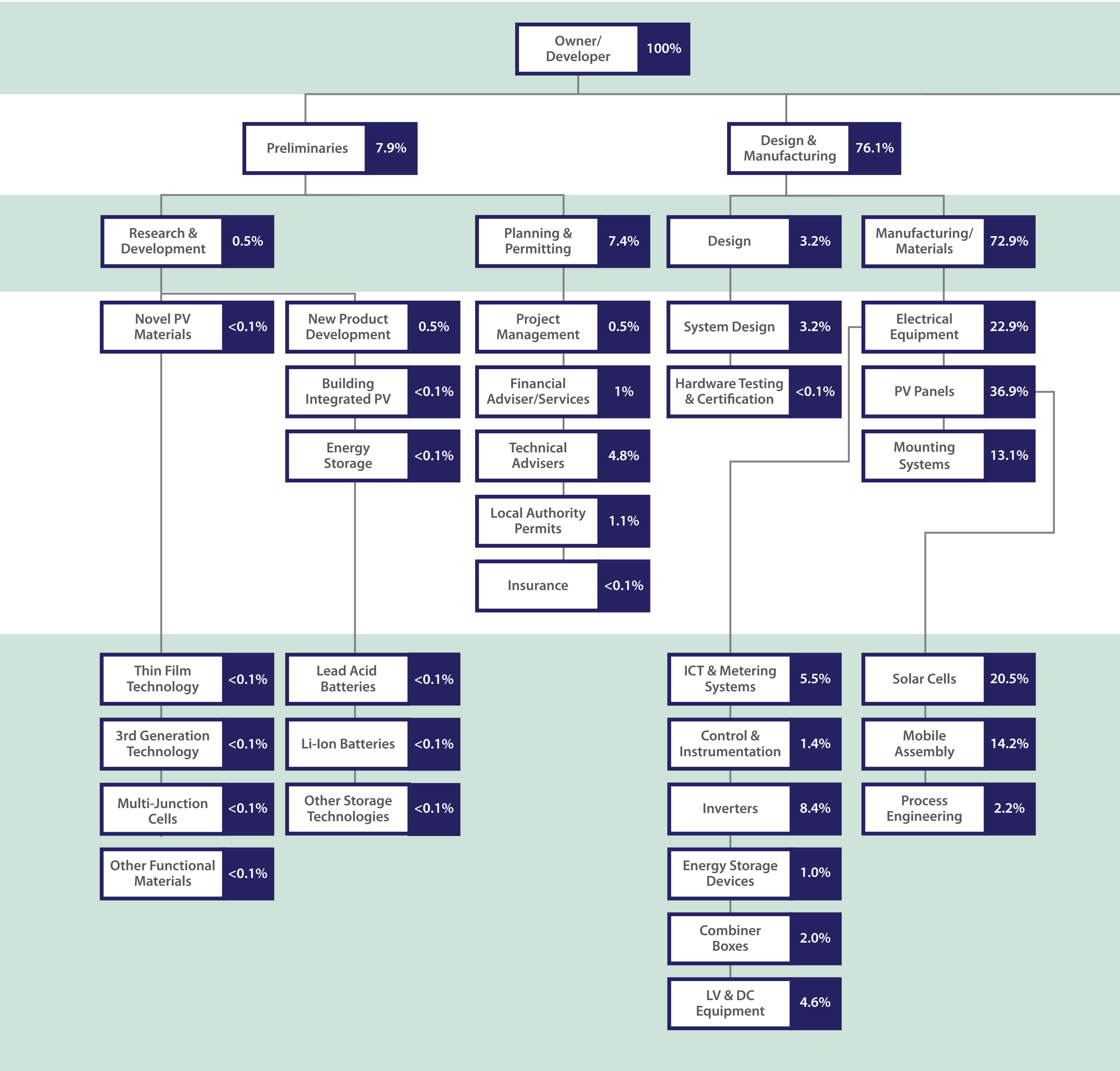
90% Operation
10% Decomissioning



90.4% Operation
9.6% Decomissioning

Rooftop Solar PV Value Distribution (% shares)

Figure 4: Value chain for rooftop solar PV systems showing the percentage of development (dark blue) or O&M (light blue) cost incurred in each value centre. The figures at higher parts of the tree are the sum of the figures shown in the parts of the tree linked by lines to them. This mapping represents the value chain from the perspective of the owner/developer.



Value Chain Levels

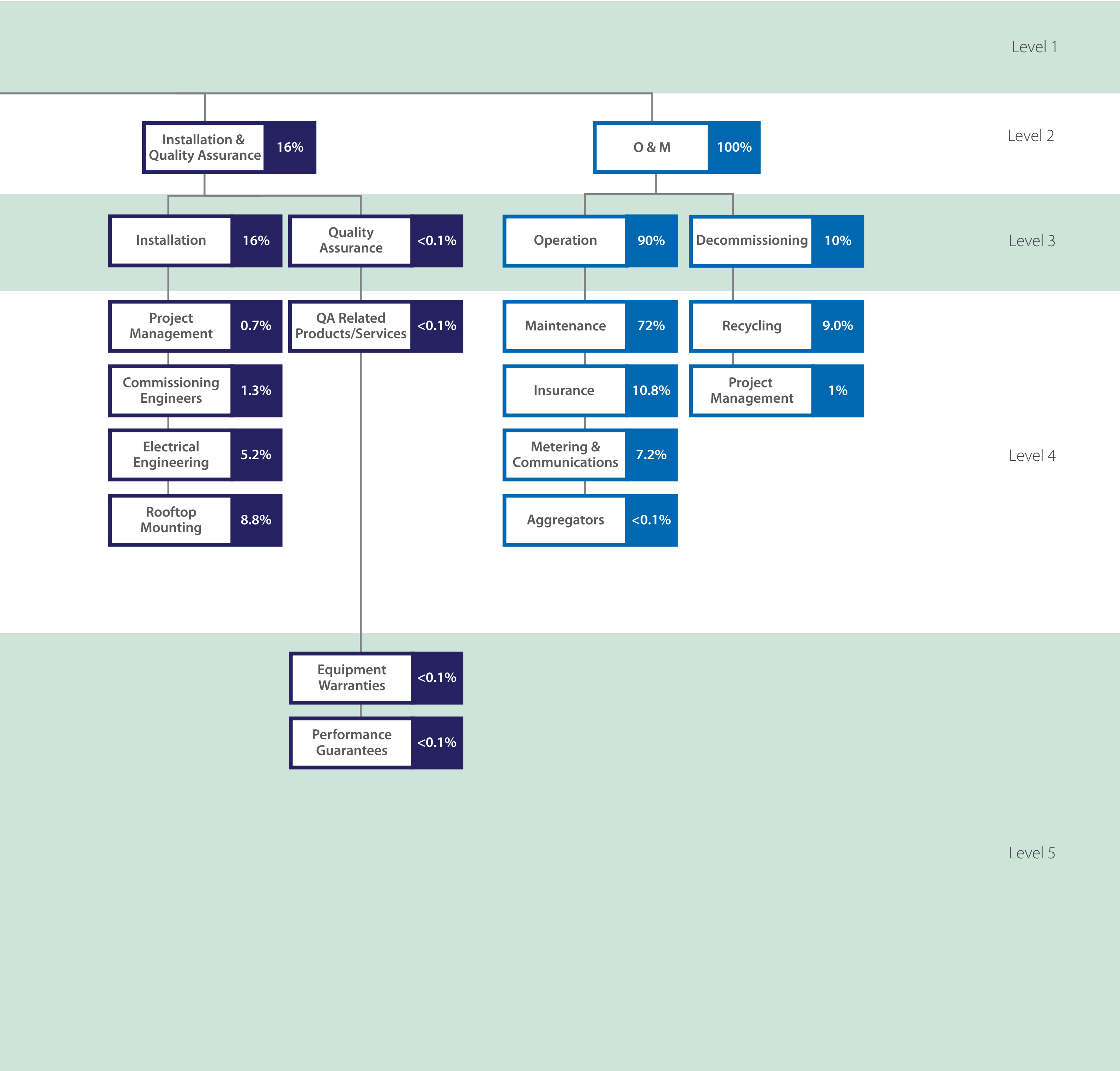
Level 1 - Ownership

Level 2 - Project

Level 3 - Lifecycle

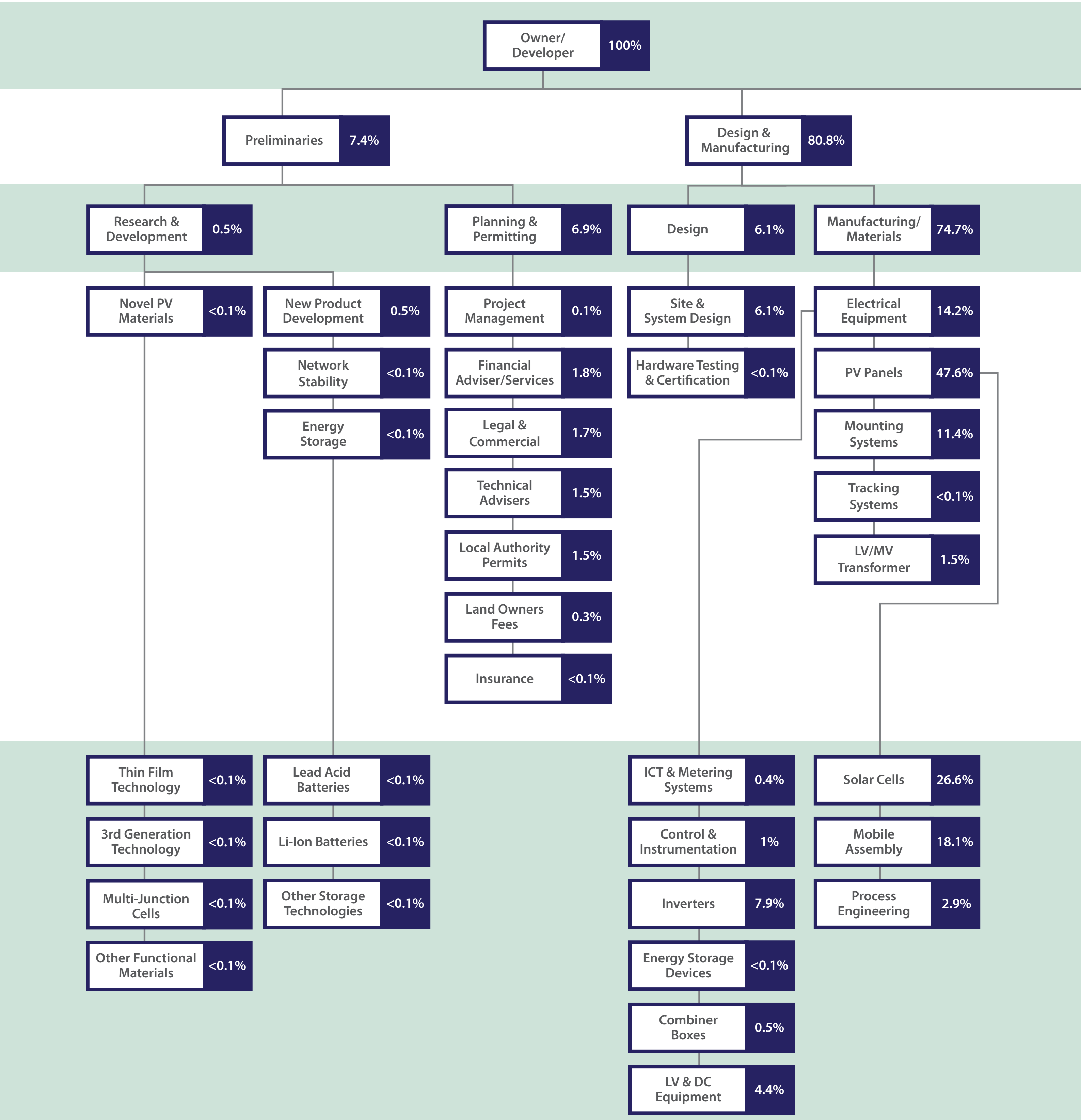
Level 4 - Key Products/Suppliers

Level 5 - Component Level



Ground Mount Solar PV Value Distribution (% shares)

Figure 5: Value chain for ground mount solar PV systems showing the percentage of development (dark blue) or O&M (light blue) cost incurred in each value centre. The figures at higher parts of the tree are the sum of the figures shown in the parts of the tree linked by lines to them. This mapping represents the value chain from the perspective of the owner/developer.



Value Chain Levels

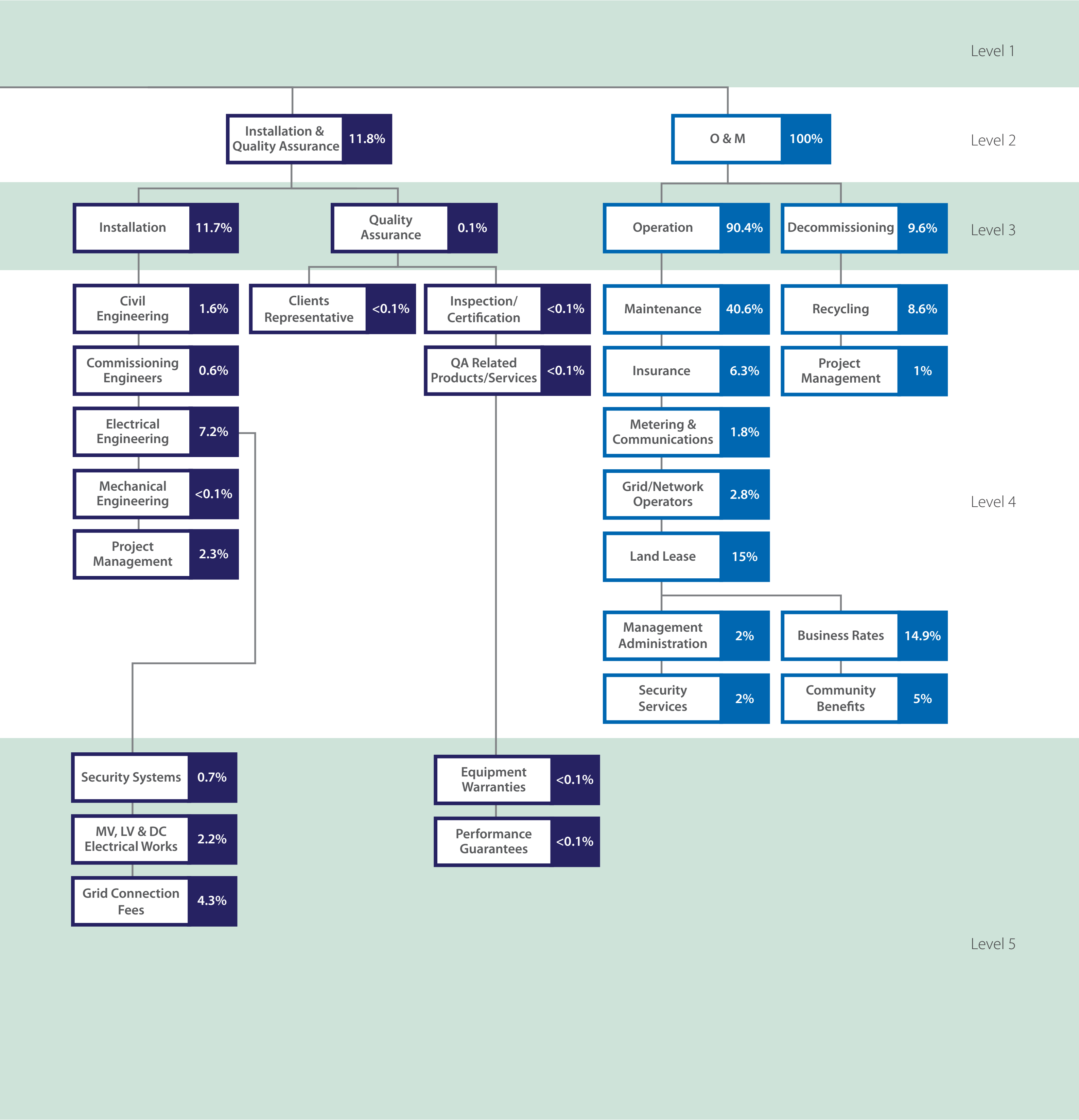
Level 1 - Ownership

Level 2 - Project

Level 3 - Lifecycle

Level 4 - Key Products/Suppliers

Level 5 - Component Level



Reflecting on the features of this mapping can generate some insights:

- *The manufacturing/materials lifecycle stage accounts for the majority of the capital investment in PV systems, demonstrating that those involved in the hardware supply chain stand to capture the most value from the global PV market. It is the solar cells themselves which account for the largest share of any value centre, but the module assembly value centre also accounts for a sizeable share. This includes the value added in assembling PV modules, but also the value in all the other materials embedded in the PV panel. Given that this accounts for between 14-18% of the overall investment it is potentially lucrative to occupy even a very minor part of this supply chain. Materials such as transparent conducting oxides (TCOs) and anti-reflective (AR) coatings, for example, constitute some of this value and suppliers of such materials stand to benefit from a growing industry seeking marginal efficiency gains and cost reductions.*

- *Electrical equipment can account for 14-23% of the capital investment in PV systems, the majority of which lies with the inverters (~8%). Around 1% of the value of capital investments in PV systems can be expected to go towards control and instrumentation systems. Although small when compared to other value centres, this constitutes a sizeable industry in the context of a global PV market.*

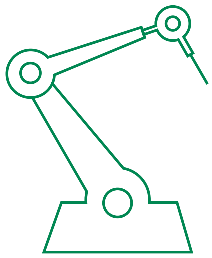
- *In the rooftop PV archetype it is assumed that energy storage devices account for just 1% of the investment – this is based on an assumption of a very small battery (1.2kWh / 1kWp) being included in a small number (<5%) of installations. This is small compared to some of the most recent high-end products for home energy storage (e.g. the Tesla Powerwall 2 is rated at 13.5kWh / 7kWp). Also, the penetration figure could be significantly higher if domestic/commercial energy storage systems become more cost effective at larger capacities and become a natural complement to PV modules.*

- *Process engineering (i.e. the development and sale of machinery/systems for manufacturing) accounts for around 2% of the investment. This highlights the opportunities in contributing to improving and optimising manufacturing techniques.*

- *Site and system design accounts for over 6% of the value of ground mount investments. Optimising system design (including integration of ancillary equipment such as tracking, monitoring and storage) can increase the competitiveness of a project and is thus a valuable service.*

- *Electrical engineering works account for 5-7% of project value, although this will vary greatly depending on the country. This is dominated by grid connection fees, thus there is a driver to limit these costs through co-location of solar farms with an existing electricity demand.*

- *Within O&M, metering and communications can account for 2-7% of annual costs and there could be space for innovation in delivering these services more effectively.*



The manufacturing/materials lifecycle stage accounts for the majority of the capital investment in PV systems, demonstrating that those involved in the hardware supply chain stand to capture the most value from the global PV market.

Prospects for Irish research and industry

4
Strengths & Opportunities

The idea of Ireland playing a role in serving the global solar PV value chain does not appear immediately obvious.

With the bulk of solar module manufacturing capacity located in Asia, and the know-how in deploying rooftop and ground mount arrays at scale hosted in European, North American and Australasian countries where uptake has been concentrated to date, it is easy to classify Ireland as a technology-taker with almost no proactive role in the value chain. However, there are several Irish companies and researchers already actively contributing across the solar value chain (see section 4.1). In addition there are other sectors, including IT, semiconductors, and materials research, in which Ireland has expertise which could be transferable to the solar PV market. Irish industry and research can be players in the PV market in several ways:

- *By contributing to niche areas of the conventional value chain (i.e. crystalline silicon solar PV) to reduce costs and improve efficiency*
- *By contributing to the development of emerging value chains of innovative new solar PV technologies and applications*
- *By developing and providing supporting services and products which enable further value-add in the wider solar PV value chain*

In order to identify the areas of strength and corresponding opportunities for Irish industry and research a comprehensive stakeholder engagement exercise was undertaken. Part of this exercise consisted of interviews with a selection of senior researchers from Irish universities, developers of innovative technologies/services in the PV sector, and stakeholders engaged in the deployment of solar PV in Ireland and elsewhere. In addition, SEAI hosted an expert stakeholder workshop to gather a wider set of views of stakeholders from across the entire solar value chain. This section summarises the key outcomes of this stakeholder engagement process, highlighting the areas where Ireland demonstrates some strength, and identifying potential opportunities in applying these strengths in the solar market.

4.1
Value Chain Strengths

The project stakeholders identified a range of areas where Ireland has particular strengths which can be transferable to the PV sector:

Research & Development

Research and Development: Across its research institutions Ireland has considerable expertise in several applicable fields:

- *Design of and research into advanced materials including nanomaterials and semiconductors. There is strong research/industry collaboration in the semiconductor sector, for example between Intel and the AMBER Research Centre at Trinity College Dublin (TCD) as well as the Tyndall National Research Institute in Cork.*
- *Novel PV materials, including for example, work on perovskite materials at the AMBER Research Centre, Dye-Sensitized Solar Cells at University College Dublin (UCD), quantum dots at Dublin Institute of Technology (DIT), and conjugated polymers at Trinity College Dublin (TCD).*
- *Thermal regulation, including research in DIT and at the Solar Energy Applications Group at TCD into phase change materials for thermal control in Building Integrated PV (BIPV).*
- *Photonics research including research into improving light harvesting and luminescence at Tyndall National Institute and CAPPA at Cork Institute of Technology (CIT).*
- *Electrochemistry research applicable to energy storage, including research on high energy density electrolytes at University of Limerick (UL).*
- *Research into wireless sensor technologies including work at the WiSAR Lab based in the Letterkenny Institute of Technology. Irish startup Wattz is exploring how wireless sensors could be powered through the integration of solar cell technology.*

Building Materials

Ireland has a history of innovation in the building materials sector, with companies such as Kingspan and CRH designing and developing new products. A strong know-how in product design, development and integration could be brought to bear in new PV applications.

Systems Integration & Optimisation

Irish design know-how also extends to system design, integration and optimisation. Integrated energy generation and storage systems have been developed at several research institutions and by Irish firms such as Instant Solar.

ICT Systems & Analytics

Irish companies are developing a range of monitoring, optimisation, control and communication systems for renewable electricity generators to support the creation of a smart grid. For example, NovoGrid, is developing grid automation solutions to maximise renewable generation output, and Solo Energy provides distributed energy storage solutions to better manage renewable generation. A dedicated industry association Smart Grid Ireland pulls together much of the Irish research and industry organisations innovating in smart grid activities. The Smart Grid Implementation Group which comprises Eirgrid and ESB Networks, as well as Smart Grid Ireland, SEAI, DCCAE, Enterprise Ireland, SFI and IDA, serves to identify research opportunities, assist in trials and testing, and develop Ireland's Smart Grid Roadmap to 2050.

Process Engineering

Know-how in the optimisation of manufacturing processes has been cultivated at several Irish research institutions and at firms such as Nines Photovoltaics who have developed novel dry etching equipment and texturing technology for silicon wafers.

High-value Manufacturing Base

Ireland has several well established manufacturing companies with expertise in the production of electronics, semiconductors, software and high-value materials engineering. This includes major semiconductor manufacturers such as Intel and Analog Devices, as well as electronic component manufacturers such as Electronic Concepts Ltd who already supply capacitors for inverters used in solar PV applications.

Onshore Wind

Given Ireland's position as one of the world leaders in onshore wind deployment, Irish

Ireland has a history of innovation in the building materials sector.

firms have unique experience and know-how across the whole project development lifecycle for wind. This includes Irish engineering and construction companies who bring project management and engineering experience, but also Irish firms with asset management and legal expertise related to renewable electricity development. Project development know-how from these disciplines is potentially transferable to the deployment of other technologies.

Education

Irish third-level institutions have an excellent track record of providing education and training in science technology, engineering and mathematics (STEM), and in supporting the work of innovative researchers and entrepreneurs active in solar PV and related technological areas. In terms of research impact, Irish universities are now in the top 1% research institutions in the world in 18 fields including environment/ecology, materials science and engineering, and the number of citations per Irish research paper exceeds that of the France, Germany and UK .

Ireland's Business Case

Enterprise Ireland and IDA Ireland have previously put forward a more general case for doing business in Ireland in renewable energy. These include Ireland's experience accommodating large penetrations of renewable electricity on its grid; a well-educated workforce with excellent track record in science, technology, engineering and mathematics (STEM); tax credits for research, development and innovation; 12.5% corporation tax rate; English-speaking; access to the European market.

Dublin Institute of Technology – cutting edge solar PV research and demonstration

The Dublin Energy Lab (DEL) based at the Dublin Institute of Technology (DIT) undertakes research in a range of solar energy related areas with a focus on Photovoltaics (PV). Activities include investigation of novel designs for solar energy concentration using PV, incorporation of PV into current state of the art devices adding autonomous power functionality, and investigation of issues relating to building integrated PV applications. Recent studies include the first outdoor characterisation of a PV powered suspended particle device switchable glazing, cellular antenna panels for building façade integration, and PV control investigation into total and partial shading and non-ideal insulation conditions. DEL's research work has been commercialised through spin-out companies, licenses and patents.

Picture Credit: Jason Clarke Photography

Nines PV – process engineering innovation

Dublin-based Nines Photovoltaics (Nines) is a solar cell technology company established in 2010, currently located at the Synergy Centre incubator for start-ups at the Institute of Technology Tallaght (ITT). Nines focuses on bringing new process technology and machinery to the solar cell manufacturing industry. It has developed a novel silicon wafer etching technology designed to allow manufacturers to increase their throughput and reduce production costs. The Atmospheric Dry Etch (ADE) tool and process provides dry etching without the downsides of alternative etching techniques.

After securing their first tool sale last year, Nines has just completed the build and qualification of a new industrially focused pilot line. This new facility allows Nines to start industrial scale demonstrations of their technology to international customers, and pursue in-house solar cell process development. According to Nines the current addressable PV market size is ~$600 million (~300ADE tools) and is expected to grow significantly in the next few years. Nines is actively engaged in promoting the opportunity to scale tool manufacturing operations here with established Irish machine builders.

Picture Credit: Nines Photovoltaics

redT – innovative battery storage solutions

redT is an energy storage technology company set up in Dublin in 2009. redT provides its customers with energy storage systems which are based on vanadium redox flow battery (VRFB) technology. The systems are deployed for use across a variety of applications including renewable energy systems, utility-scale grid balancing, off-grid telecom sites, integration with diesel generating sets, and for sites with unreliable grid connection. Its storage solution has been used in tandem with solar PV as part of the European Commission's PV CROPS project in Evora, Portugal.

redT have worked with the University of Limerick to commercialise research into electrolyte optimisation. They are also carrying out research to improve stability and working to develop a new low-cost high-performance membrane. Red T Energy has secured international patents (around 30 -35 worldwide) mostly related to the cell stack..

Picture Credit: redT

4.2
Value Chain Opportunities

The project stakeholders identified a range of opportunities for Ireland to capture some share of the wider PV value chain. These are presented below, grouped based on the three areas identified at the start of section 4.

Conventional Value Chain

- **Process Engineering:** There have been considerable gains worldwide in silicon wafer manufacturing in recent years but there is still scope for minimising silicon losses, lowering operating costs and increasing throughput. There is potential for Irish research and industry to export expertise in optimising silicon wafer manufacturing, either via licensing of IP or even through the manufacture of equipment such as the ADE technology being developed by Nines Photovoltaics. Innovation in manufacturing techniques could also potentially be applied to other PV technologies.

- **Design & Optimisation:** Integrated systems using existing products such as PV modules and battery storage could be designed and assembled in Ireland, adding value through innovative design.

- **Installation & Maintenance:** A growing domestic PV market would present opportunities for local jobs in trades and professional services. There could be opportunities for new Irish jobs in installing, assuring, monitoring, testing, repairing and cleaning solar PV systems, providing security for ground mount solar PV sites, and in recycling systems at the end of their useful life. This would help to develop the local skills base needed to capture value in other related areas of the value chain where there is export potential..

There is potential for Irish research and industry to export expertise in optimising silicon wafer manufacturing.

Emerging Value Chains

- **Building Integrated PV:** The Building Integrated PV (BIPV) market has shown promise for many years but, despite modest success for a handful of products, has yet to develop into a mass market. Given Irish experience developing building materials and integrated energy systems there are opportunities to design and potentially fabricate high-value integrated PV products such as glazing, facades and roofing products. The stringent requirements regarding new dwelling energy use in Irish building standards (Part L) means that there could be a good domestic market for such products. It is not clear yet how large the future global BIPV market could be with some analysts speculating it could reach over $20bn by the early 2020s.[20] Developing products and expertise by stimulating a domestic market in BIPV could unlock opportunities for Irish business in other countries.

- **Novel PV materials:** There is considerable know-how in Irish research institutions in the development and application of emerging photovoltaic technologies such as Dye-Sensitized Solar Cells, perovskites, quantum dots and conjugated polymers. A challenge these emerging materials face is in identifying appropriate applications where they can be competitive, given the dominance of silicon and thin film technologies in the rooftop and ground mount markets. One promising application is in integrating these materials into consumer electronics, autonomous devices and wireless sensor networks as they tend to be easier to process and manipulate than conventional PV materials, but research must overcome challenges in material costs, stability and poor efficiency. Where research can address these shortcomings there is an opportunity for licensing IP or potentially in the synthesis of such materials.

- **Optimising Functional Materials:** As well as investigating lower cost semiconductor materials many module manufacturers seek efficiency gains and

20. n-tech, 2015

cost reductions from other functional materials in their products. Work at Irish research institutions into other materials such as anti-reflective coatings, transparent constructing oxides for thin film PV, and phase change materials for thermal regulation in concentrated solar PV could help contribute to further efficiency gains in emerging technologies.

- **Storage & Monitoring:** Know-how in electrochemistry in Ireland is already being applied to develop new storage solutions. The battery storage market is poised for major growth with demand for home, business and off-grid storage solutions swelling. There could be opportunities for Irish companies in system design, high-value component manufacture and IP licensing. In particular, strengths in Irish research in battery storage, wireless sensors, and control and monitoring systems could allow for opportunities in designing and developing off-grid storage products with remote condition monitoring systems.

Supporting Services

- **Smart Grid Products & Services:** As solar PV becomes cost competitive in more and more markets its penetration in the generation mix will grow, introducing challenges in managing its intermittency. These challenges present opportunities to exploit Irish strengths in ICT systems, data analytics and telecommunications which will enable more effective use of electricity generated from PV. This includes intelligent monitoring and control systems, energy storage management systems, demand side management (DSM) controls, and active grid control systems. In this area, Irish companies can apply the practical experience gained in managing high levels of intermittent renewables and growing experience in integrating storage solutions, to take a technical lead in developing and testing new products for the EU market. The development of the DS3 programme as well as the future roll out of smart meters in Ireland will also present opportunities in this space.

- **Financial Services:** There will be opportunities for Irish financial services companies, already active in the renewable energy market, to develop specialist solutions in areas such as solar PV project financing and insurance for manufacturers, installers, developers and home owners. There could also be opportunities for fund and asset management based companies in Ireland (e.g. solar YieldCo).

NovoGrid – optimising output for renewable generators

Novogrid is a spin-out company from the school of electrical and electronic engineering in University College Dublin (UCD) established in 2014. It develops a range of grid automation solutions targeted at maximising renewable generation output onto the grid. Its control platform, AVA (Active Voltage Assessment), dynamically modifies the generator's electrical output in synergy with the grid variations enabling the generator to export more electricity and increase annual revenue. Detailed power flow analysis conducted by NovoGrid as part of an SEAI-funded project, under its Research, Development and Demonstration programme, determined that its AVA platform could improve the annual output of a $5MW_p$ solar farm by 0.6% via a reduction in electrical network losses.

Picture Credit: Nick Bradshaw, Fotonic

The size of the prize for Irish organisations

5 Value Proposition

The appeal of exploring niche areas of the solar value chain where Irish organisations can apply their know-how is that capturing even a minor share of a very large and rapidly growing global market could generate many millions of euros in revenues for Irish business

Irish organisations can also position themselves to capture a significant share of the domestic solar PV market as it grows and maximise the benefits for Irish businesses, communities and society as a whole.

In order to get some sense of the possible size of the prize for Irish business and research, this section considers scenarios for the Irish and EU[21] solar PV markets out to 2030. The analysis is intended to present an 'order of magnitude' assessment only, as opposed to forecasting the future market sizes based on specific policy, economic and technical assumptions.

21. EU27 + UK

5.1
Uptake Scenarios

Estimating future uptake of solar PV in Ireland is difficult without developing a modelling framework incorporating technology cost projections, policy and regulatory impacts, and assumptions regarding future energy service demands and infrastructure investments.

As an alternative to this a simple top-down approach has been applied to develop illustrative, but technically feasible uptake scenarios for solar PV in Ireland based on EU deployment scenarios presented by the International Energy Agency (IEA). As noted above, these are not forecasts, rather they are scenarios that are intended to give a sense of the potential range of deployment for the technology based on IEA scenarios. These scenarios are then used to derive some indicative figures for the market value that Irish organisations could potentially capture by 2030.

i) EU Scenarios

The two EU deployment scenarios used in this illustration are based on the market projections presented in the IEA's Energy Technology Perspectives:[22]

- *The '6 degree scenario' (6DS), which is largely an extension of current trends. Primary energy demand and CO2 emissions would grow by 60% from 2013 to 2050. This provides a modest estimate of the potential for PV.*

- *The 'high renewables scenario' (hi-RenS) illustrates the potential role for renewables in the power sector that could deliver an emissions trajectory consistent with at least a 50% chance of limiting the average global temperature increase to 2°C. This scenario is in line with relevant policy commitments made through the Paris Agreement.*

These scenarios represent modest and ambitious growth in EU solar PV deployment respectively. The 6DS reaches 123GW$_p$ installed capacity in the EU by 2030 while the hi-RenS[23] reaches 192GW$_p$ as part of a wider mix of renewable energy technologies across Europe.

ii) Irish Scenarios

As noted above, feasible Irish uptake scenarios[24] have been derived by applying a top-down approach to the IEA EU scenarios. Population has been used as a simple proxy[25] for distributing deployment on a pro-rata basis. The Irish share of the EU's population is expected to be around 1% in 2030.

Under the 'high renewables scenario', it is assumed that Ireland catches up with other Member States that have already achieved significant PV uptake and reaches 1% of the total installed capacity in the EU hi-RenS. Under these assumptions this scenario would result in 1.9GW$_p$ of solar PV being deployed by 2030 (assuming appropriate measures are taken to accommodate this penetration of solar PV on the grid alongside other intermittent renewable generators, including interconnection, deployment of storage, and demand side management).

Under the more modest uptake scenario, it is assumed that Ireland captures 1% of the new (i.e. 2017-2030 deployment) installed capacity in the 6DS. This would amount to 0.29GW$_p$ of solar PV deployed by 2030. .

In both scenarios, it is assumed that rooftop systems would represent 51% of the installed capacity in Ireland by 2030 (in line with the split currently realised in the UK[26]), but 60% across the EU

Table 2: *2030 PV capacity assumed under the two IEA scenarios.*

GW (installed by 2030)	EU	IRE
6DS	123	0.29
hi-RenS	192	1.9

Realisation of these illustrative scenarios would depend on a wide range of economic, policy, technical and regulatory factors in support of PV deployment that have not been modelled in this study.

22. IEA, 2014a
23. The hi-RenS figure used here is taken from a subsequent update to the ETP 2014 analysis (IEA, 2014b)
24. Note again that these scenarios are not forecasts of Irish PV deployment and are not underpinned by any assumption about what policies or measures may be introduced. Rather they are technically feasible scenarios derived from EU-level projections.
25. Irish electricity consumption per capita is close to the EU average (see the World Bank electric power consumption indicators: http://bit.ly/2kKXcZQ)

5.2
Market Size Scenarios

By combining these uptake scenarios with assumptions regarding future PV system costs it is possible to estimate the corresponding value of the markets for each application.

Capital cost assumptions for solar PV systems between 2017 and 2030 are set out Table 3, based on a 2015 report by KPMG on solar PV in Ireland.[27] O&M costs are based on the assumption that annual O&M costs are 2% of total capital investment[28] between 2017 and 2030..

Table 3: *Assumed change in turnkey system prices for solar PV between 2017 and 2030 (KPMG, 2015)*

Capex €/kW (2016 prices)	2017	2030
Rooftop Solar PV	1,750	1,575
Ground Mount Solar PV	1,187	742

The resulting market size estimates for Ireland and the EU are shown in Tables 4 and 5

Table 4: *Estimated solar PV market size in Ireland under the two scenarios in 2030 (€m in 2030)*

Market Size in 2030 (€m/ year)	Rooftop		Ground Mount	
Scenario:	6DA	hi-RenS	6DS	hi-RenS
Capital Investment	28	196	15	97
Operation & Maintenance	5	31	3	17
Total Solar PV Market	**33**	**227**	**18**	**114**

Table 5: *Estimated solar PV market size in the EU under the two scenarios in 2030 (€m in 2030)*

Market Size in 2030 (€m/ year)	Rooftop		Ground Mount	
Scenario:	6DS	hi-RenS	6DS	hi-RenS
Capital Investment	1,340	6,138	570	1,928
Operation & Maintenance	529	1,814	207	702
Total Solar PV Market	**1,869**	**7,952**	**777**	**2,630**

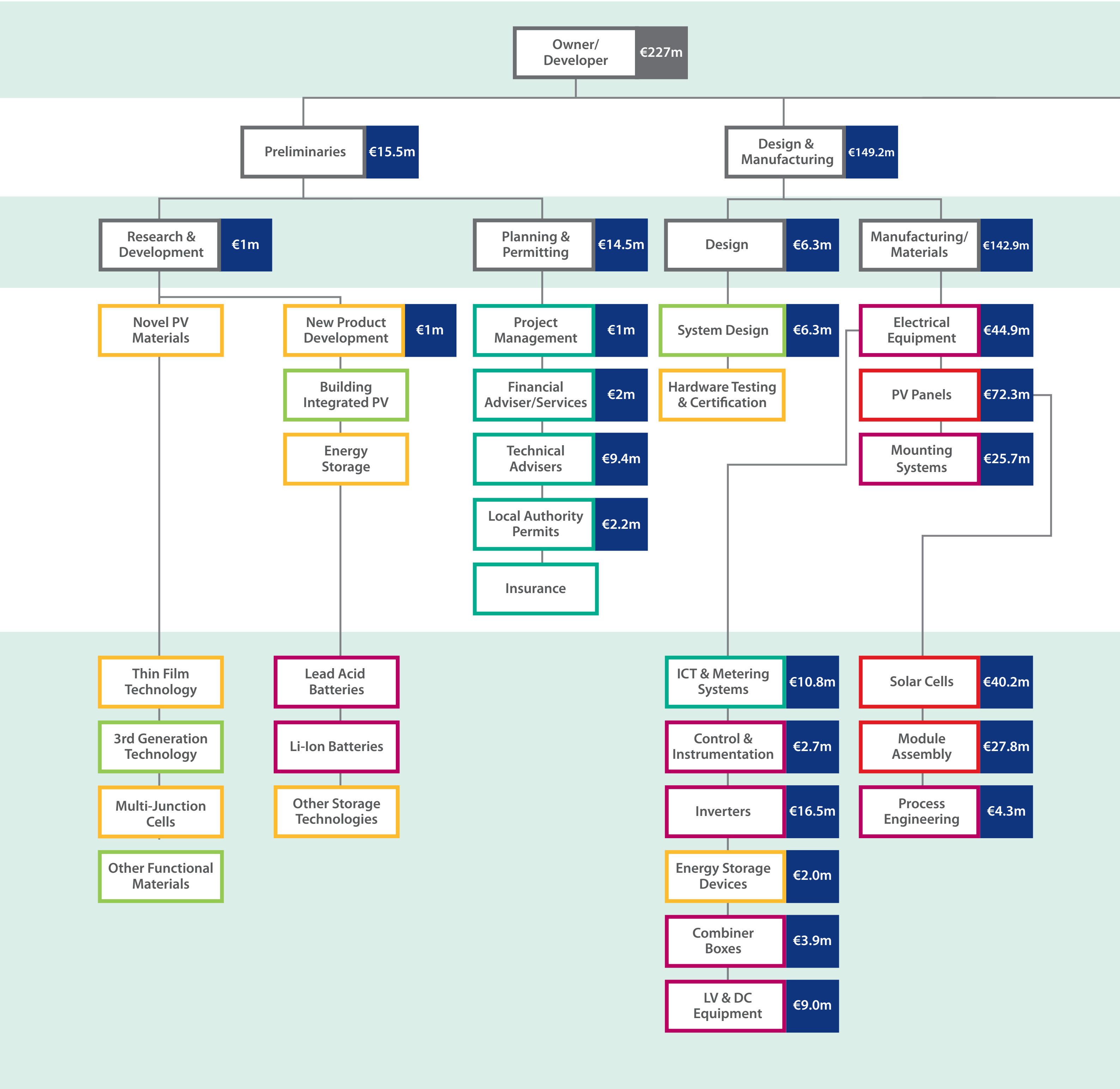
By multiplying these market values by the shares for each value centre in the distribution maps in Figure 4 and Figure 5 it is possible to allocate the investment across the various value centres in the value chain for each application. This is shown for the Irish hi-RenS in the two maps overleaf. These diagrams show the annual expenditure (in 2030) across the value chain due to Irish investment in rooftop and ground mount solar PV. Where no value is shown next to an area of the value chain, the percentage of initial capital or annual maintenance cost is less than <0.1%. The value distribution maps for the Irish 6DS and the two EU scenarios can be found in Appendix A.

In addition to the market size estimates the various value centres in the maps are marked with colours which denote the capacity of Irish business and research to capture market share. The colours chosen for each value centre are based on the outcomes of the stakeholder engagement exercise, a consideration of number of incumbents, and for the wider EU market a preference for local suppliers. Further discussion on this is set out in section 5.3

26. As of July 2016 according to DECC Solar PV deployment (https://www.gov.uk/government/statistics/solar-photovoltaics-deployment)
27. KPMG, 2015
28. EPRI, 2010

Rooftop Solar PV (Irish Market Value Breakdown €m/yr)

Figure 6: Expenditure in 2030 across the value chain due to investment in rooftop Solar PV systems in Ireland under the hi-RenS. The figures at higher parts of the tree are the sum of the figures shown in the parts of the tree linked by lines to them. Development costs are in dark blue, O&M costs in light blue. The colours of the value centres in levels 4 and 5 indicate the capacity of Irish business and research to capture market share.

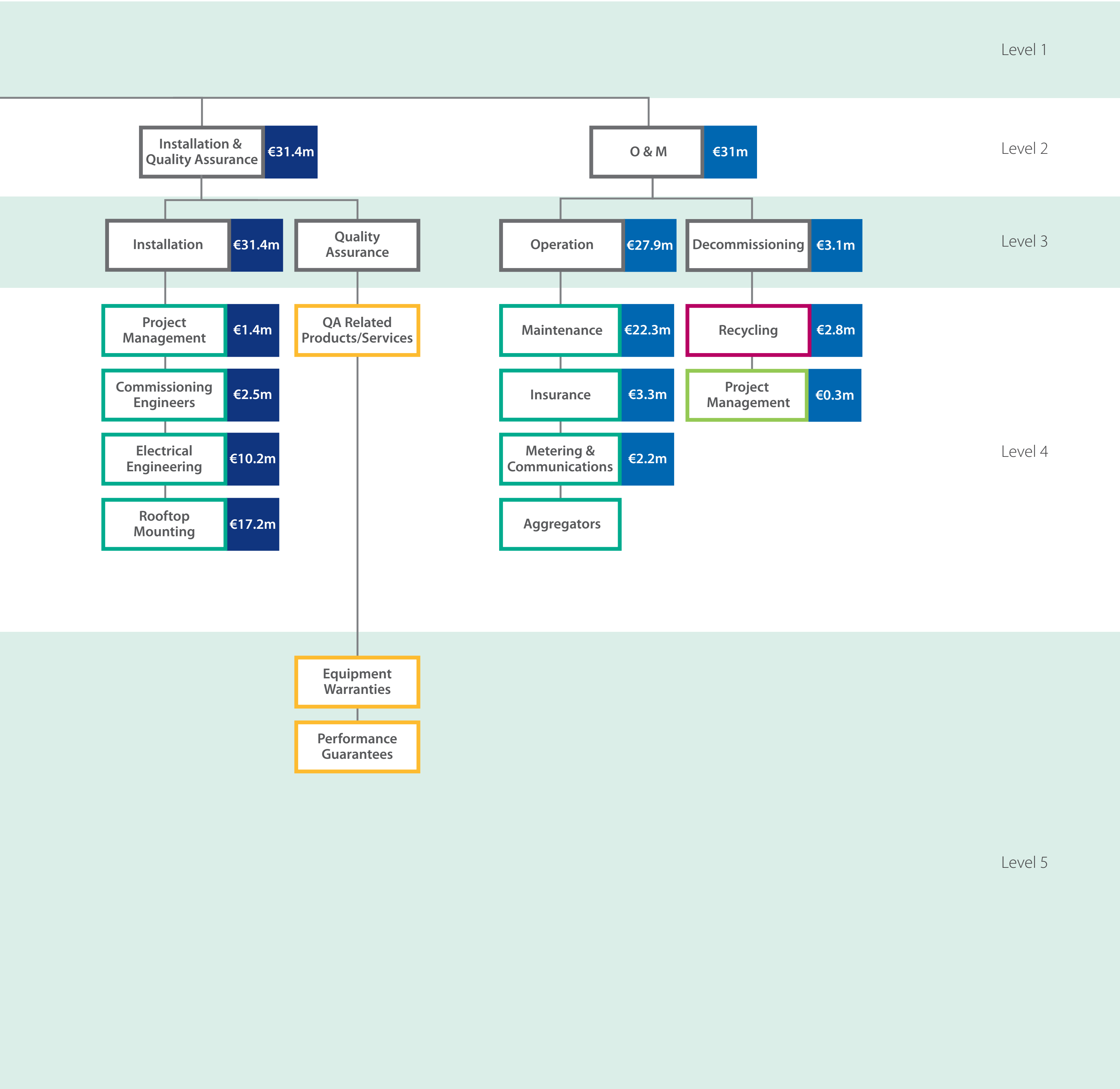


Value Chain Levels

Level 1 - Ownership
Level 2 - Project
Level 3 - Lifecycle
Level 4 - Key Products/Suppliers
Level 5 - Component Level

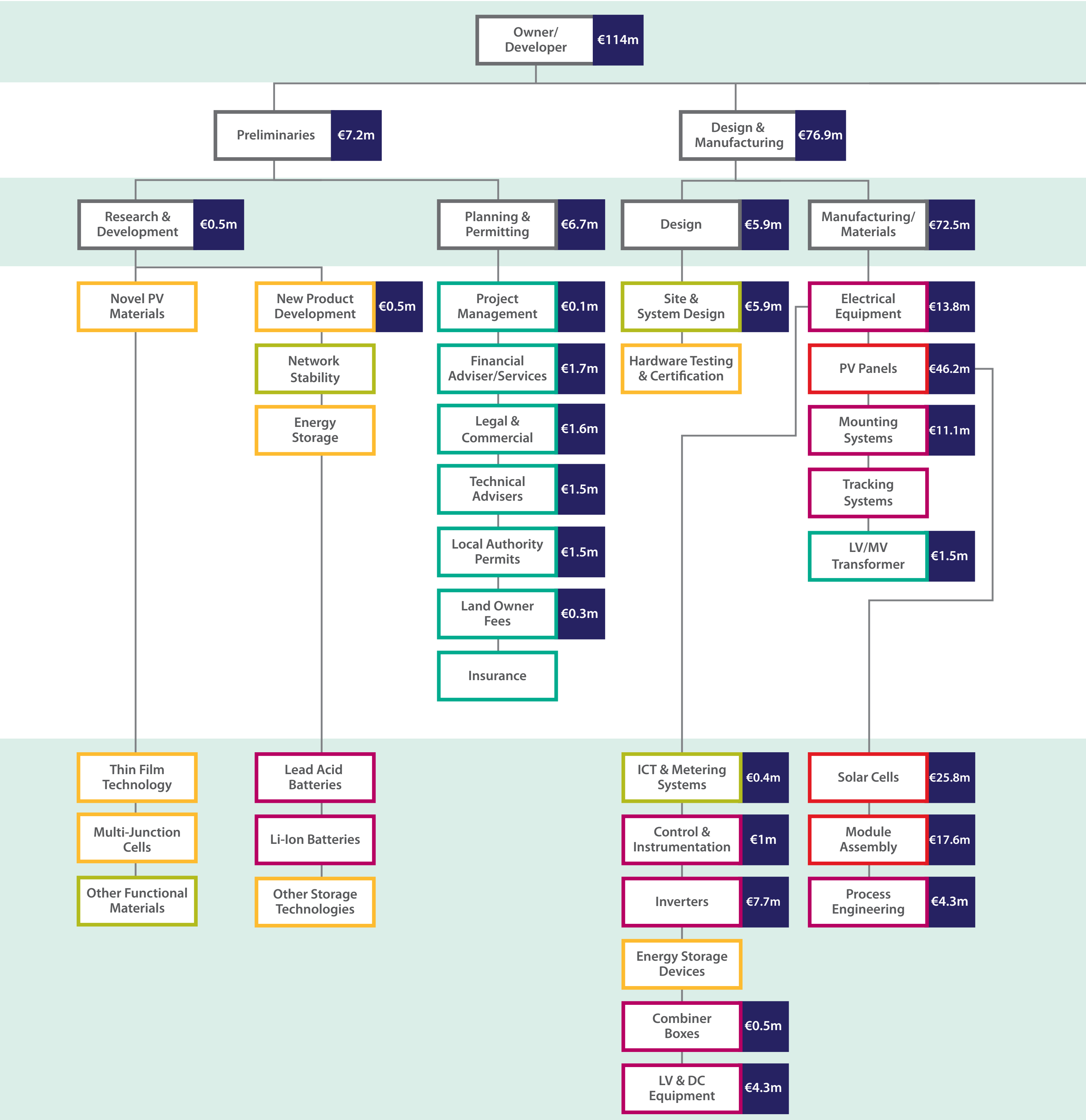
Capacity to Capture Market Share

- Very well positioned
- Well positioned
- Averagely positioned
- Less well positioned
- Not well positioned



Ground Mount Solar PV (Irish Market Value Breakdown €m/yr)

Figure 7: Expenditure in 2030 across the value chain due to investment in ground mount Solar PV systems in Ireland under the hi-RenS. The figures at higher parts of the tree are the sum of the figures shown in the parts of the tree linked by lines to them. Development costs are in dark blue, O&M costs in light blue. The colours of the value centres in levels 4 and 5 indicate the capacity of Irish business and research to capture market share.

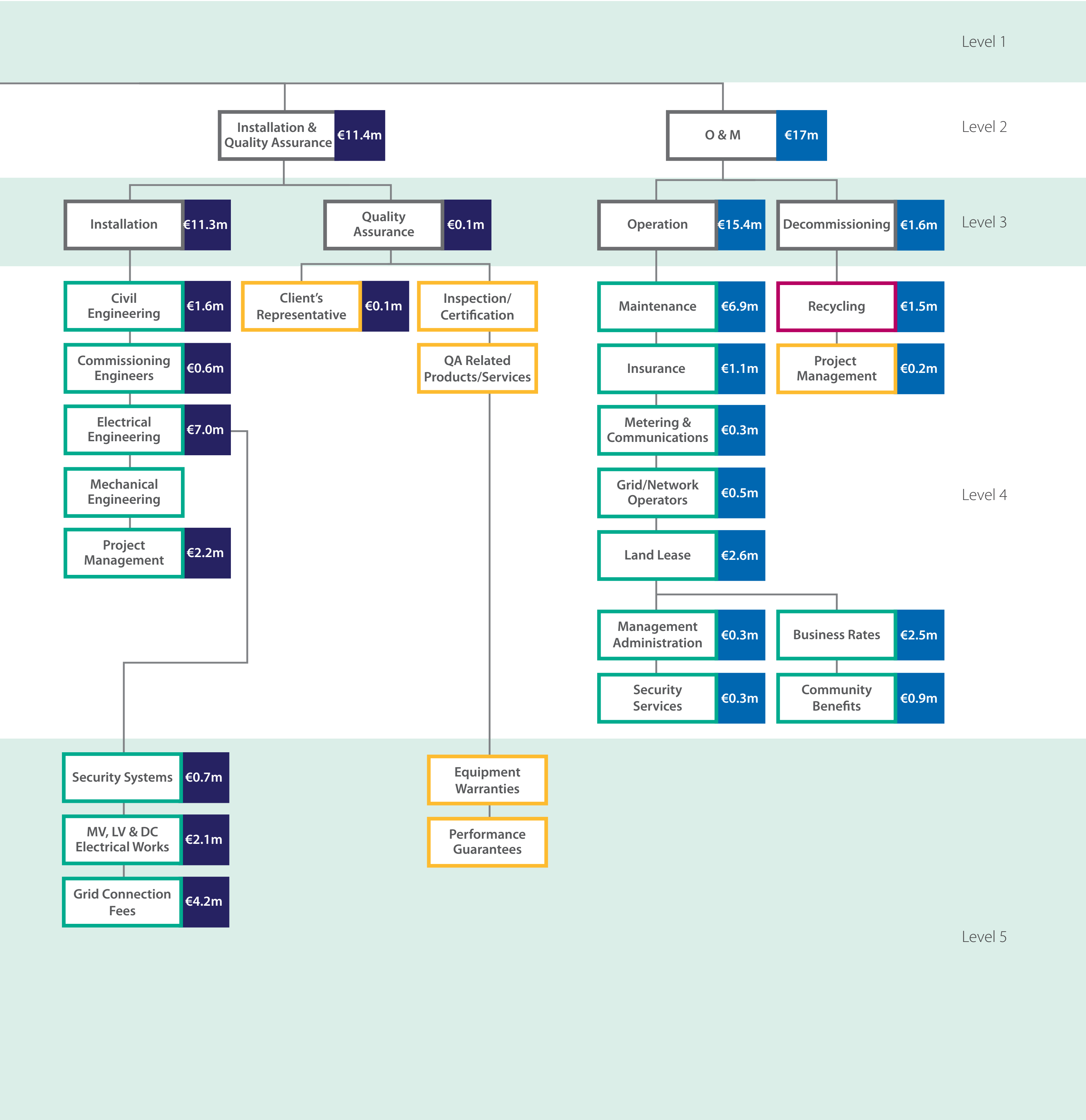


Value Chain Levels

Level 1 - Ownership
Level 2 - Project
Level 3 - Lifecycle
Level 4 - Key Products/Suppliers
Level 5 - Component Level

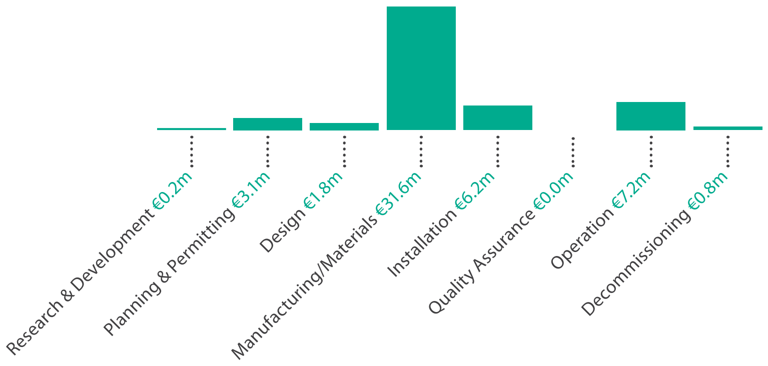
Capacity to Capture Market Share

- Very well positioned
- Well positioned
- Averagely positioned
- Less well positioned
- Not well positioned



These charts provide a breakdown of the total annual expenditure on solar PV in Ireland and the EU in each stage of the technology development lifecycle from research and development through to decommissioning under the two scenarios. This shows that the value of the EU PV market could potential reach over €10bn per year by 2030, and the Irish domestic market could be up to €340m per year. Note that over €4.5bn of the EU market is in segments other than manufacturing/materials so an absence of a strong manufacturing sector does not preclude a country from capturing a share of the market.

Figure 8: *Breakdown of expenditure in the Irish and EU solar PV market in 2030 under the two scenarios. The IEA's '6 degree scenario' (6DS) and the 'high renewables scenario' (hi-RenS) represent futures with low and high ambitions respectively with regards to solar PV deployment in Europe.*



Scenario: 6DS

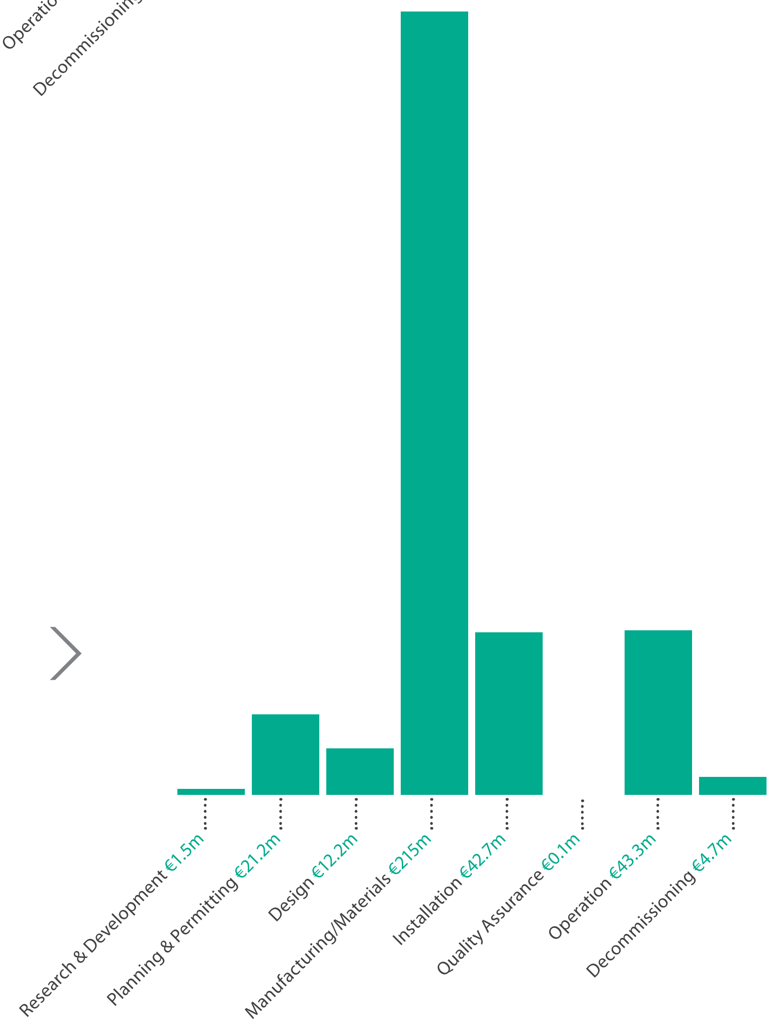
Total Irish Solar PV Market Size in 2030

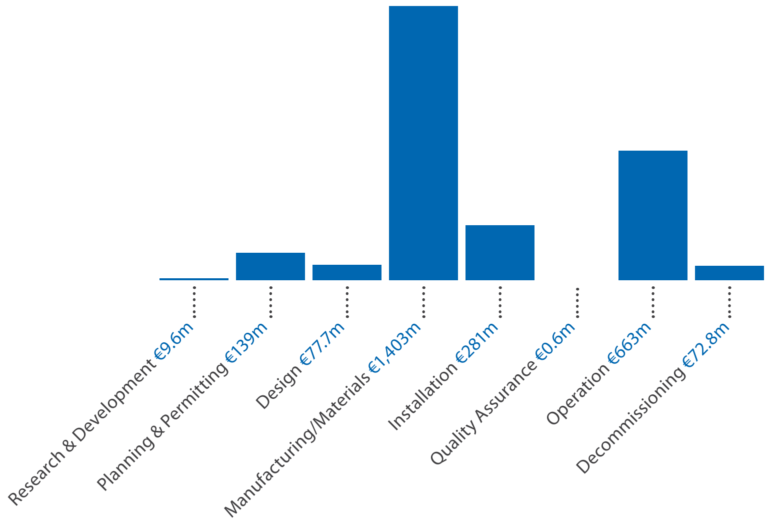
€51m/yr

Scenario: hi-RenS

Total Irish Solar PV Market Size in 2030

€341m/yr





Scenario: 6DS

Total EU Solar PV

Market Size in 2030

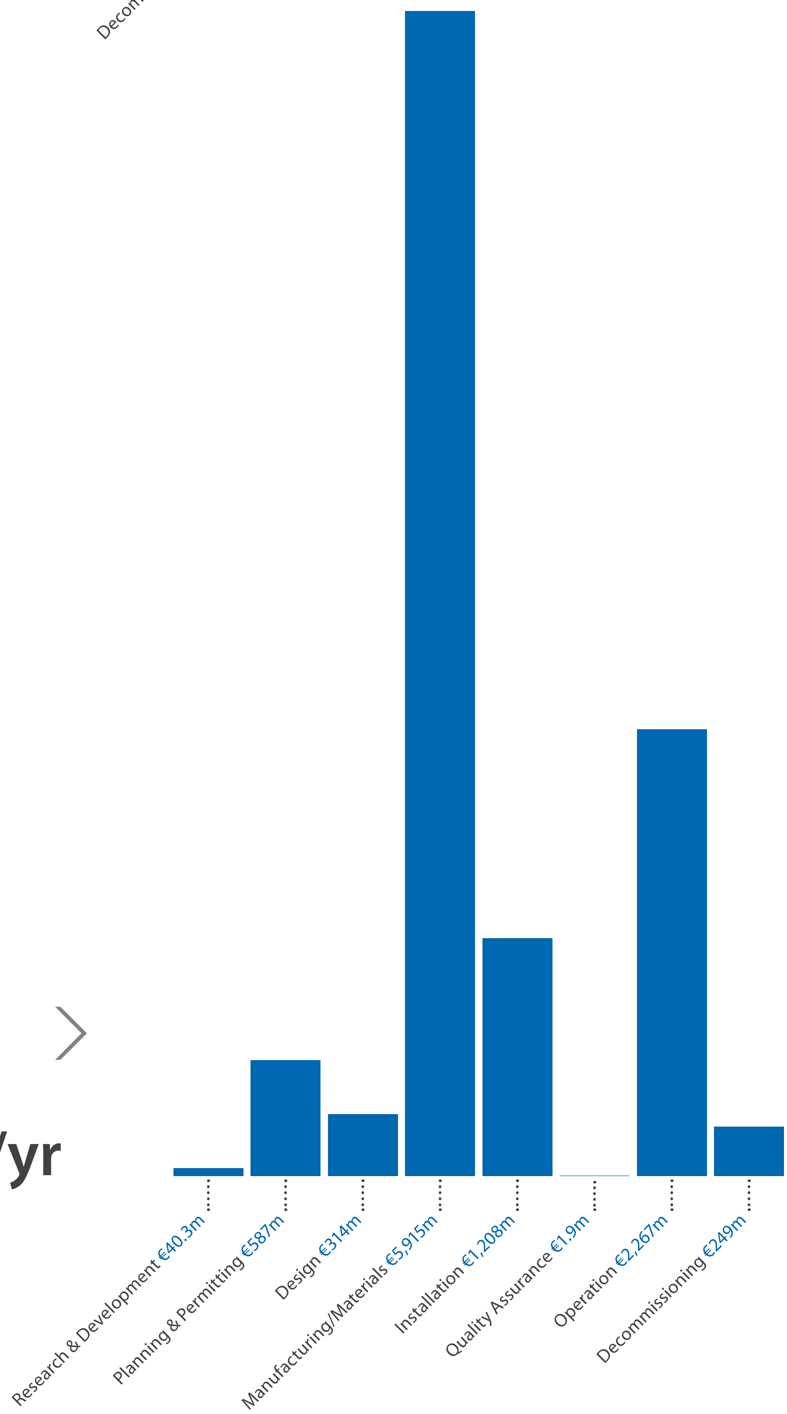
€2,646m/yr

Scenario: hi-RenS

Total EU Solar PV

Market Size in 2030

€10,582m/yr



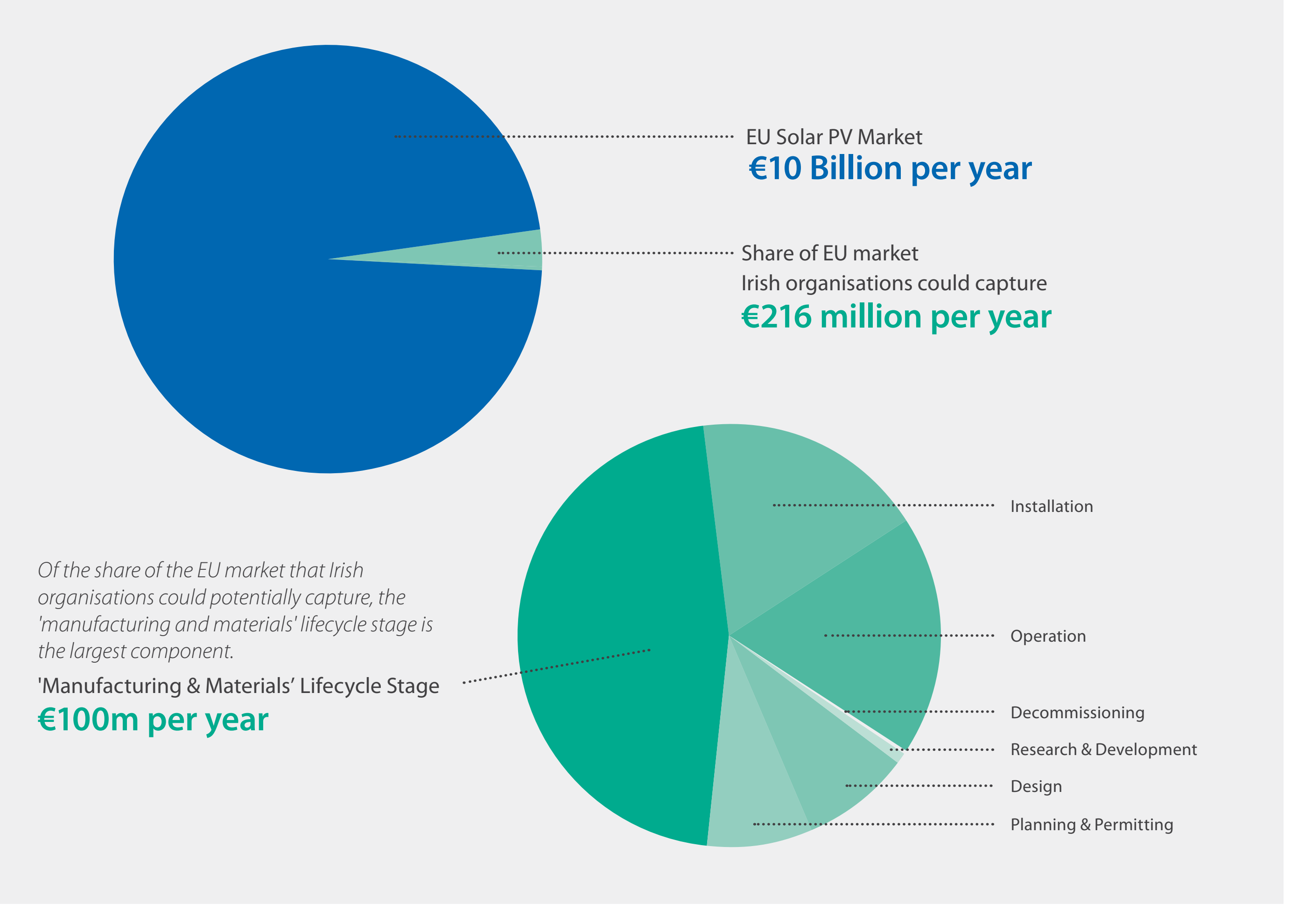
5.3
Irish Market Share

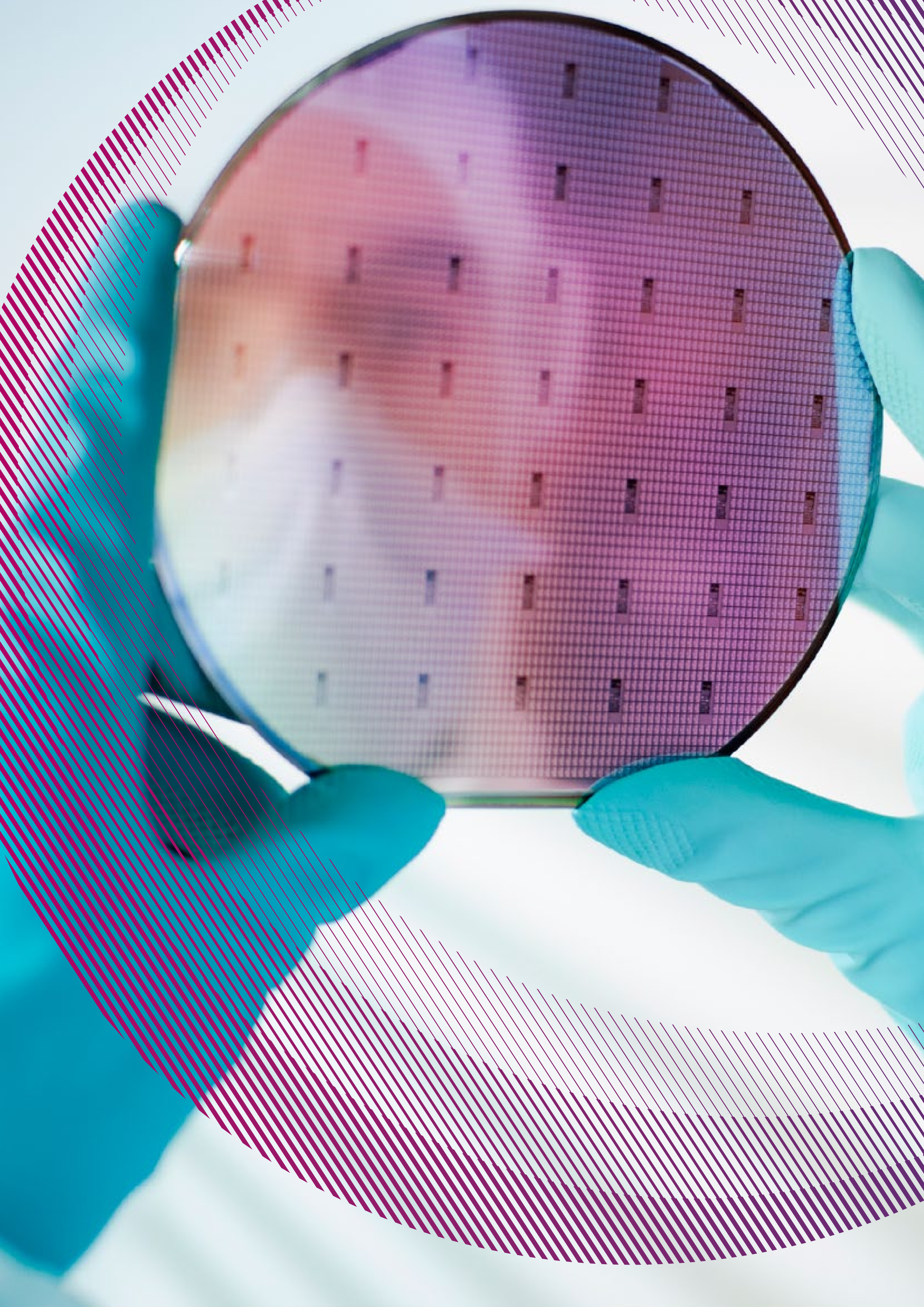
As noted in the previous section, the various value centres in Figures 6 and 7 have been identified by a colour-coded rating corresponding to how well-positioned Irish business is considered to be in terms of capturing a share of the value in that segment.

In order to assess the size of the market for Irish organisations in each value centre these qualitative classifications were translated into corresponding percentage estimates of the share of the segment which realistically Irish industry could capture, bearing in mind the influence of incumbents and preferences for local suppliers in the wider EU market. Combining these estimates with the market size estimates set out in Figures 6 and 7 gives a sense of the potential size of the prize for Irish businesses if they were to actively pursue relevant opportunities in the solar PV industry.

Based on this method of estimation, the total potential value that Irish organisations could capture of the EU solar PV market by 2030 under the two scenarios is estimated to be between €42-€216 million per year. The biggest share of this is in the 'manufacturing and materials' lifecycle stage (€20-€100 million per year) particularly in ICT and metering systems, energy storage devices and process engineering. lifecycle stage (€20-€100 million per year) particularly in ICT & Metering systems, energy storage devices and process engineering.

Figure 9: The potential EU Solar PV market in 2030 (blue) and the potential value Irish organisations could capture under under the high renewables scenario (green) and a breakdown of the Irish share of the EU market by lifecycle stage' in the high renewables scenario.





6 Priorities & Next Steps

The exercise of exploring where Ireland's strengths lie in the PV value chain (and the corresponding value that could be unlocked from exporting these strengths) helps to identify priority areas for development and support.

Working with the project stakeholders several priority areas were highlighted where there is significant value to be captured and Irish research and industry is well-positioned. Four of the most promising areas identified were:

- **Building Integrated PV:** Although the value chain maps indicate that only a small portion of spending on conventional PV systems will contribute to R&D in BIPV, the map does not capture the potential value of a future BIPV market in its own right. Stakeholders identified the opportunity of developing products and expertise by stimulating a domestic market in BIPV to unlock potential for Irish business in other markets. Supporting R&D focused on integrating PV technology within building materials should be an area of priority for Irish solar research. Ireland's existing building materials industry could potentially offer a channel for exploiting this research in applications, so providing opportunities for industry and researchers to share expertise would be valuable. Supporting demonstration projects which incorporate such products into exemplar buildings could also be a useful step in standardising products such as these.

- **Materials R&D:** Given the anticipated scale of the global PV market it would be a missed opportunity were Ireland not to apply its world leading materials research to applicable areas of the value chain. This includes research into novel PV materials (such as perovskites, quantum dots and conjugated polymers), other semiconductor materials, phase change materials, energy storage, nanomaterials and transparent conducting oxides. Research on such materials and their applications in the PV sector should continue to be supported.

- **Process Engineering:** There is potential for Irish research and industry to export expertise in optimising silicon wafer manufacturing. While Ireland does not have a strong manufacturing base compared with other countries, there is scope to develop technology and IP for optimising processing, in what is potentially a very large market. Innovation in manufacturing techniques could also potentially be applied to PV technologies other than crystalline silicon.

- **Smart grid products and services:** The value chains maps for Europe (see Appendix A) suggest that the market for ICT and metering systems for solar PV could be over €300m per year by 2030. This is identified as Ireland's strongest area for export potential in the conventional PV supply chain and is thus an area which deserves attention. This is also an important field at a domestic level, already being applied in managing high penetrations of wind generation in Ireland and integrating with storage solutions. Consideration should be given to funding research projects which focus on developing Ireland's capability in smart grid products and services, specifically tailored to managing generation and consumption of electricity from PV to minimise the impact on the grid.

There are several positive steps which can be taken by public agencies, the research community and industry to help unlock the opportunities in these priority areas and in others. These include:

- **Establishing a Research / Industry Forum:** A solar PV forum bringing together industry and research communities on a regular basis could generate opportunities for collaboration and knowledge transfer. Initiating such a forum could serve as a first step in identifying strategic areas of focus for the sector in Ireland, and potentially develop a case for funding a dedicated research cluster in solar PV research and applications.

- **RD&D Support:** A wide variety of solar PV research and demonstration projects have been supported through SEAI's RD&D programme to date. Targeted support for both fundamental research and projects demonstrating viability in the priority areas identified in this report would represent the most effective use of supports.

- **Addressing Barriers to Deployment:** Stakeholders interviewed highlighted non-financial barriers to the development of a domestic solar PV market. A healthy home market makes developing and testing new products and services (and cultivating the skillset needed to deploy them) more straightforward. It also opens up opportunities for local trades and businesses to capture value, particularly in planning, design, installation and maintenance of PV systems. At the rooftop scale non-financial barriers which could be addressed include reviewing the limits on system size before planning permission is required and ensuring appropriate standards and training are introduced to maintain quality. For ground mount systems stakeholders identified complications in the grid connection process as the primary barrier which needs to be reviewed.

- **Enterprise Support:** Funding and supports for start-ups is available via Enterprise Ireland and the opportunity areas in the PV value chain identified in this study should be recognised as relevant for Ireland. Stakeholders called for greater collaboration between Irish research and industry in developing new enterprises in the solar PV space and both groups should seek out these opportunities and avail of enterprise supports.

- **Informing on Solar PV:** Solar PV will be one of the most important energy technologies in meeting global climate commitments and there is strategic value in ensuring that solar PV features as part of relevant engineering curricula in Ireland. Stakeholders identified a value in PhD funding for research exploring PV materials and applications. In addition it is also important that information on solar PV is readily available to the general public to help inform any investment decisions. SEAI will endeavour to provide appropriate updated guidance on the technology for interested stakeholders.

7
Conclusion

Solar PV is currently the fastest growing power generation technology worldwide and is positioned to become one of the most important global energy technologies of the 21st century.

The analysis in this report suggests that the market in the EU alone could be over €10bn per year by 2030 and potentially up to €340m in Ireland. If Irish industry and research could claim even a portion of this market in a few key areas of the wider value chain it could generate significant new business.

There are already several Irish businesses and researchers contributing to global solar PV supply chains but there is a lot more scope for innovation drawing on existing strengths. Consultation with stakeholders from research and industry identified several areas of opportunity in the wider solar PV value chain where Ireland is well-positioned to unlock considerable value, including:

- **Conventional Value Chain:** By contributing in niche areas of the conventional (i.e. crystalline silicon) solar PV value chain, including innovation in process engineering, designing and optimising integrated systems, and installation and maintenance of PV systems.
- **Emerging Value Chains:** by contributing to the development of innovative new solar PV technologies and applications including Building Integrated PV, novel PV materials, other functional materials, and storage and monitoring technologies.
- **Supporting Services:** By developing supporting services and products which enable further value-add in the wider solar PV value chain, including smart grid products and services.

The total potential value that Irish organisations could capture of the EU solar PV market by 2030 under two deployment scenarios is estimated to be between €42-€216 million per year. This gives a sense of the potential size of the prize for Irish business if they actively pursue relevant opportunities in the solar PV industry.

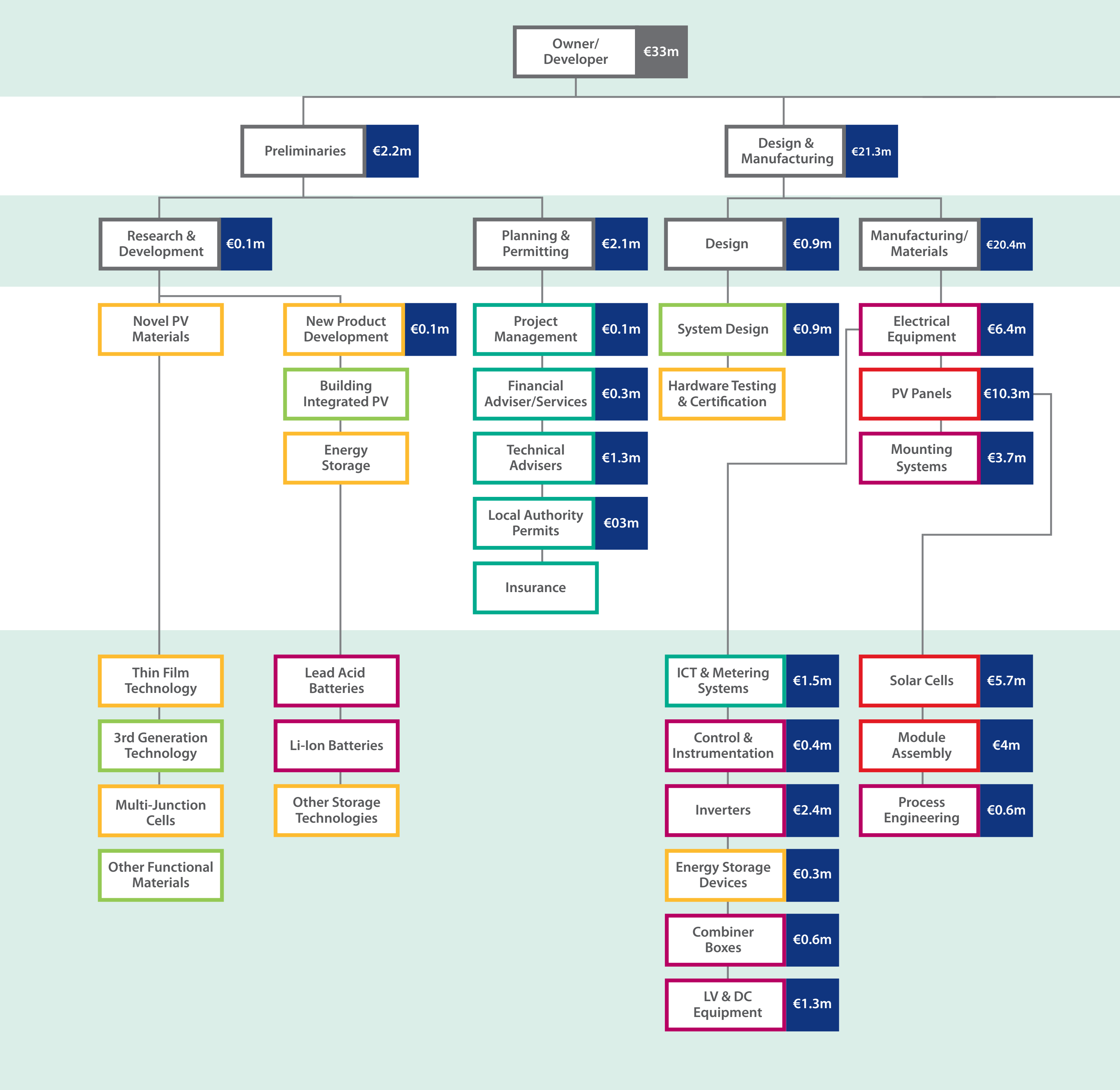
Working with the project stakeholders several priority areas were highlighted where there is significant value to be captured and Irish research and industry is well-positioned. The most promising priority areas identified are Building Integrated PV, materials R&D with applications in solar PV, process engineering, and smart grid products and services. There are several positive steps which can be taken by public agencies, the research community and industry to help unlock the opportunities in these priority areas and in others. These include the need to establish a solar PV research/industry forum for sharing knowledge, providing targeted RD&D support, and addressing barriers to domestic PV deployment to allow local supply chains to develop.

Finally, given that solar PV is poised to become one of the most important energy technologies of the 21st Century, there is a need to ensure that Irish citizens have access to good information on the technology to help inform any investment decisions, and there is also strategic value in ensuring that solar PV features as part of relevant engineering curricula in Ireland.

Appendix A

Rooftop Solar PV (Irish Market Value Breakdown €m/yr)

A.1: Expenditure in 2030 across the value chain due to investment in rooftop Solar PV systems in Ireland under the 6DS. The figures at higher parts of the tree are the sum of the figures shown in the parts of the tree linked by lines to them. Development costs are in dark blue, O&M costs in light blue. The colours of the value centres in levels 4 and 5 indicate the capacity of Irish business and research to capture market share.

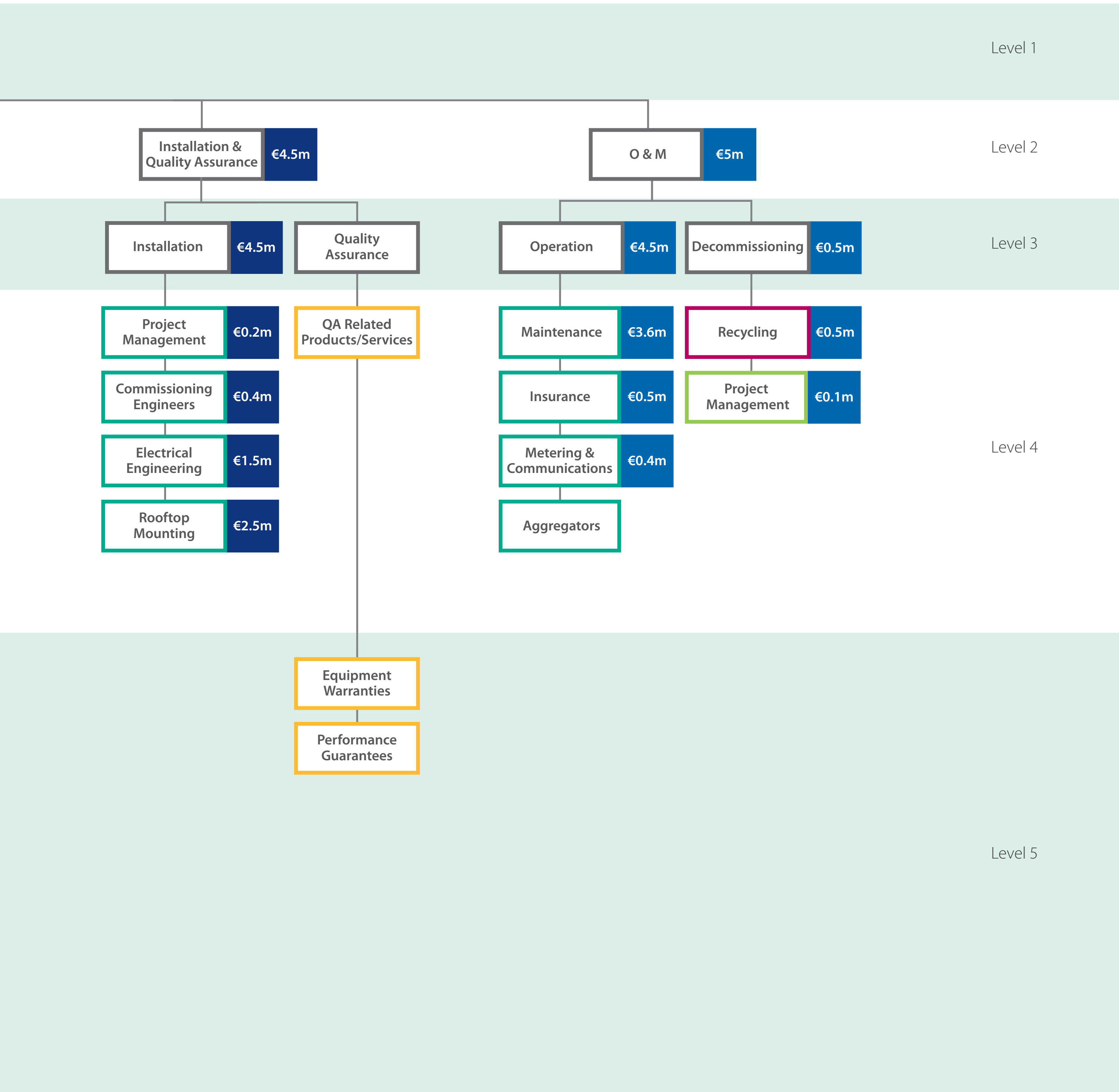


Value Chain Levels

Level 1 - **Ownership**
Level 2 - **Project**
Level 3 - **Lifecycle**
Level 4 - **Key Products/Suppliers**
Level 5 - **Component Level**

Capacity to Capture Market Share

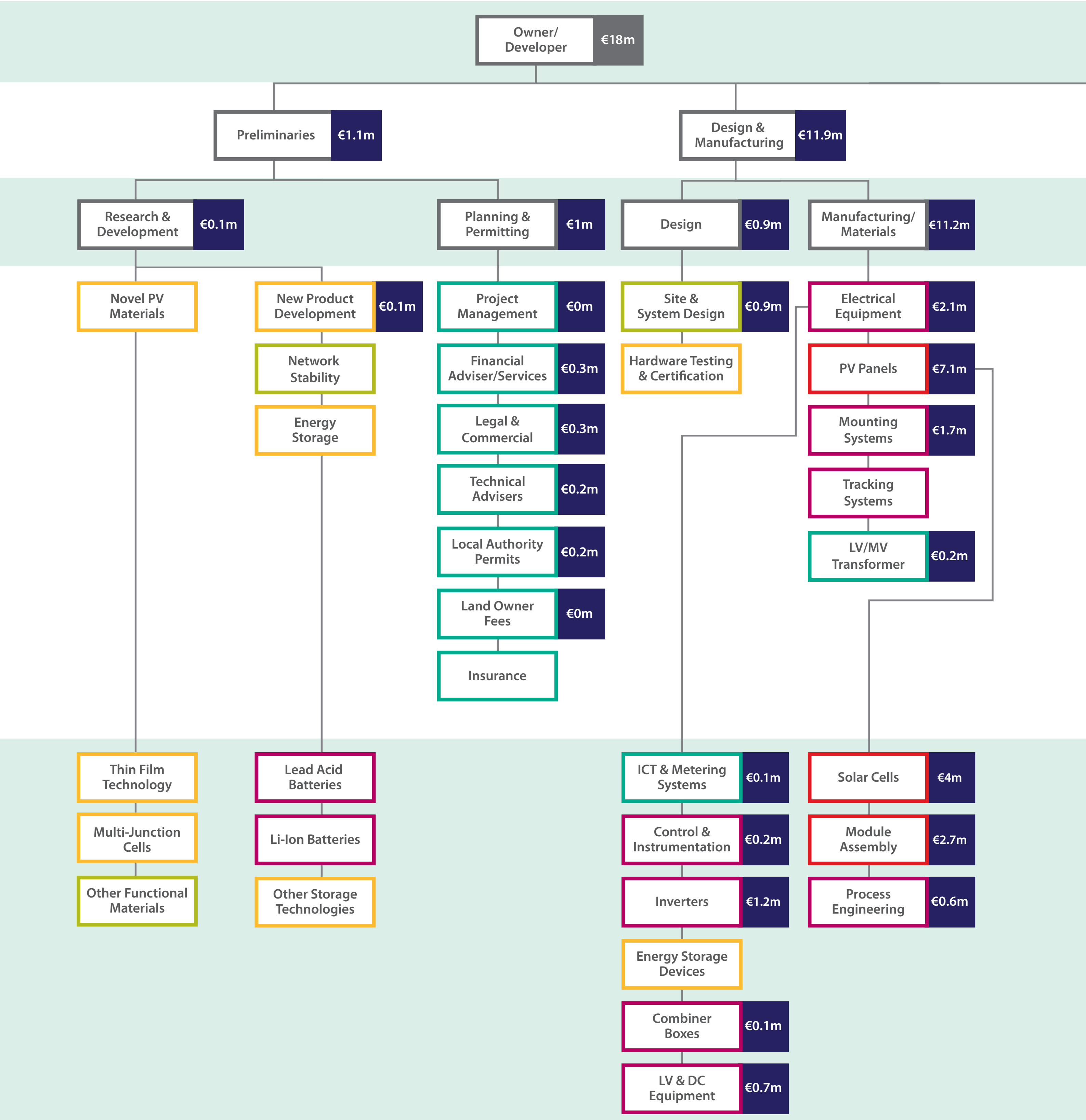
- Very well positioned
- Well positioned
- Averagely positioned
- Less well positioned
- Not well positioned



Appendix A (contd.)

Ground Mount Solar PV (Irish Market Value Breakdown €m/yr)

A.2: Expenditure in 2030 across the value chain due to investment in ground mount Solar PV systems in Ireland under the 6DS. The figures at higher parts of the tree are the sum of the figures shown in the parts of the tree linked by lines to them. Development costs are in dark blue, O&M costs in light blue. The colours of the value centres in levels 4 and 5 indicate the capacity of Irish business and research to capture market share.



Value Chain Levels

Level 1 - **Ownership**

Level 2 - **Project**

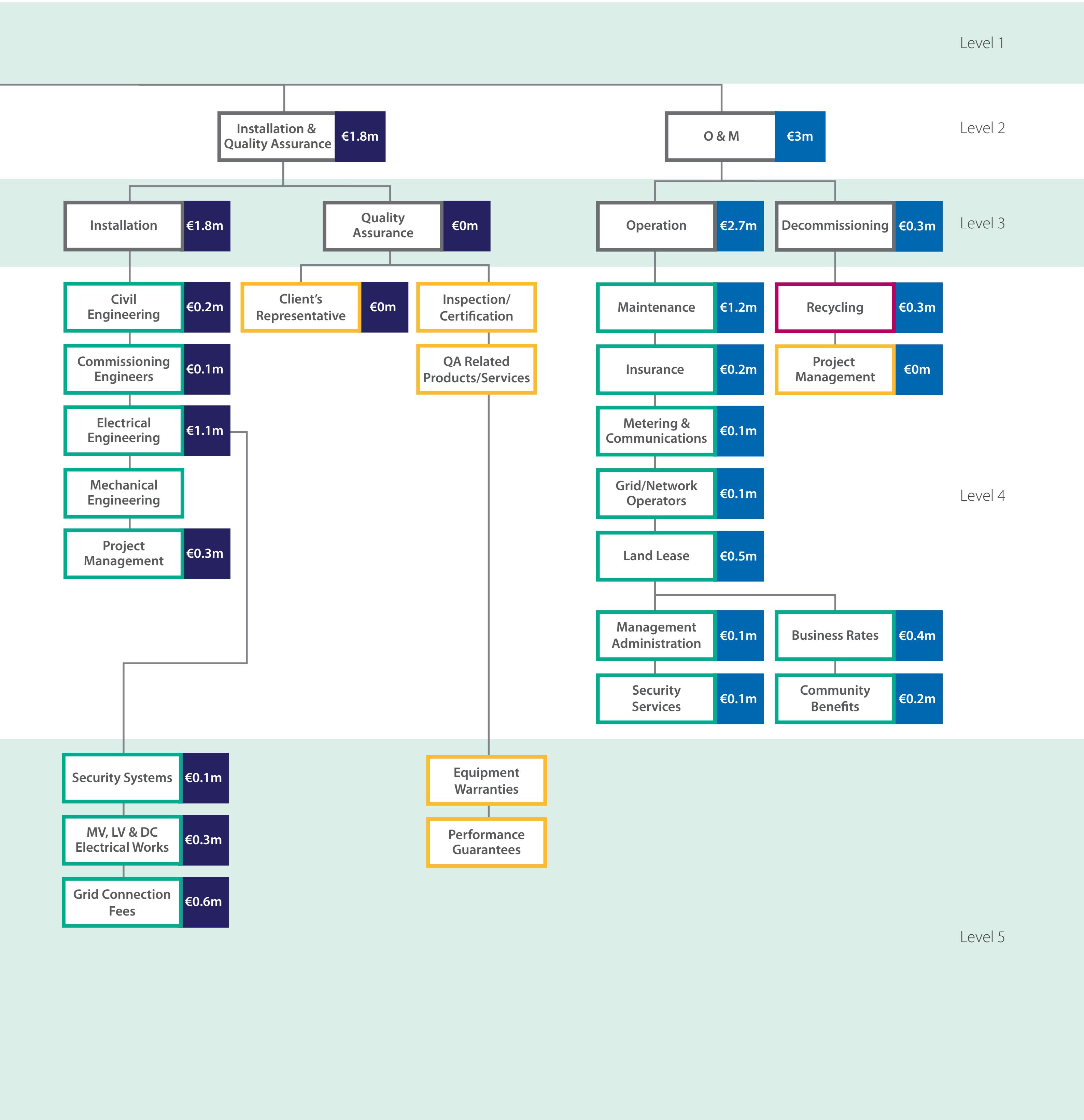
Level 3 - **Lifecycle**

Level 4 - **Key Products/Suppliers**

Level 5 - **Component Level**

Capacity to Capture Market Share

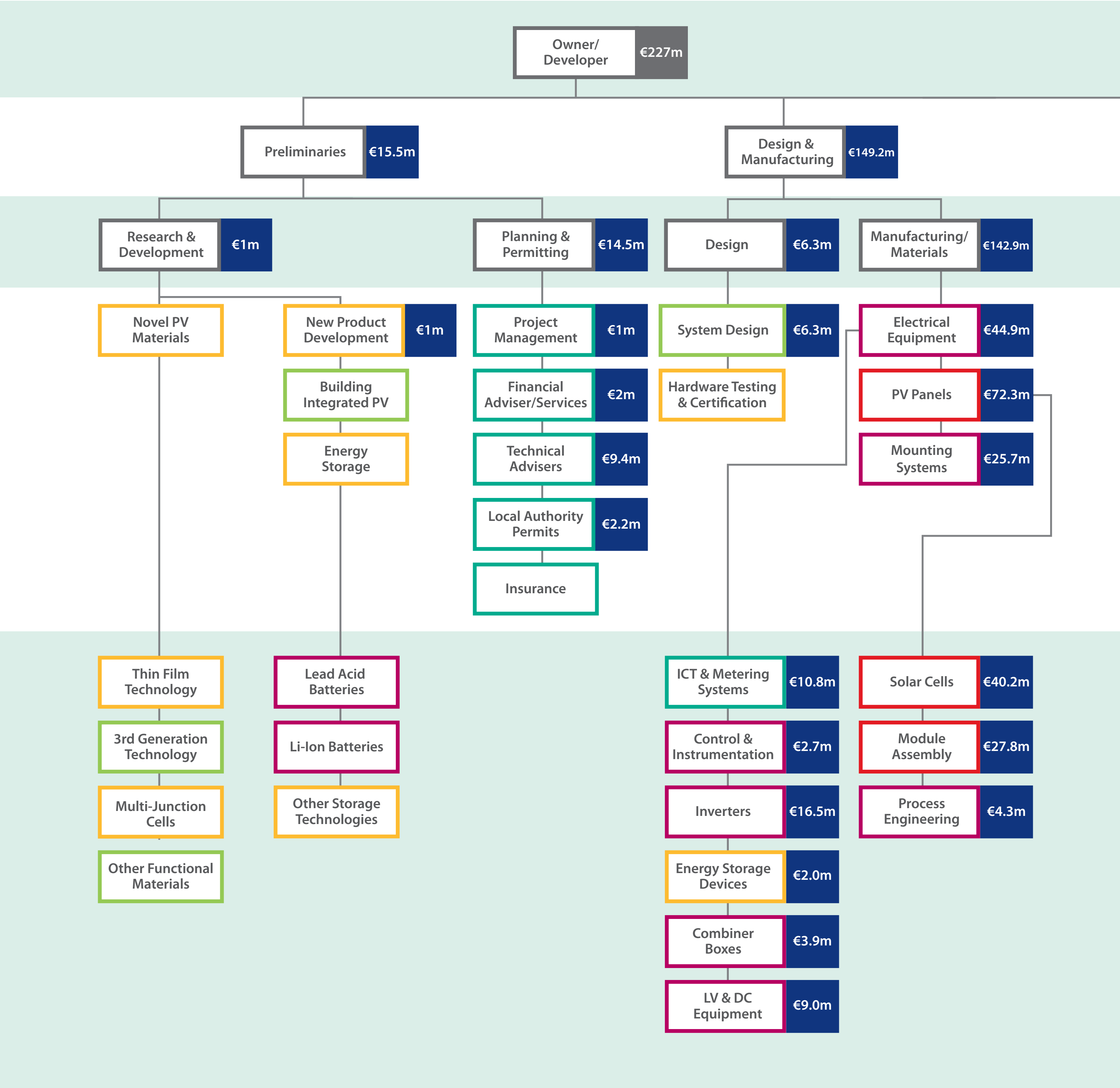
- Very well positioned
- Well positioned
- Averagely positioned
- Less well positioned
- Not well positioned



Appendix A (contd.)

Rooftop Solar PV (Irish Market Value Breakdown €m/yr)

A.3: Expenditure in 2030 across the value chain due to investment in rooftop Solar PV systems in Ireland under the hi-RenS. The figures at higher parts of the tree are the sum of the figures shown in the parts of the tree linked by lines to them. Development costs are in dark blue, O&M costs in light blue. The colours of the value centres in levels 4 and 5 indicate the capacity of Irish business and research to capture market share.

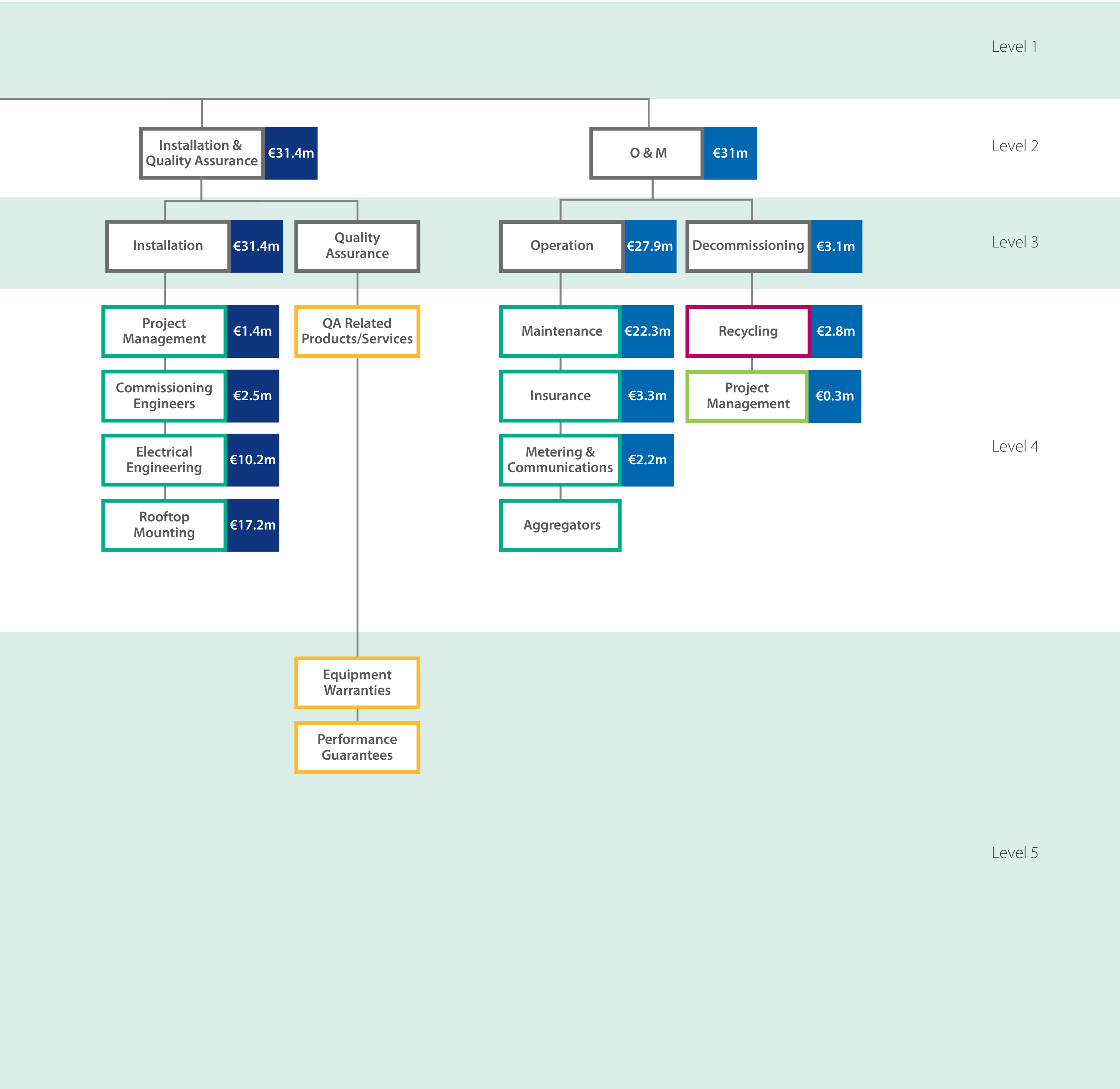


Value Chain Levels

Level 1 - **Ownership**
Level 2 - **Project**
Level 3 - **Lifecycle**
Level 4 - **Key Products/Suppliers**
Level 5 - **Component Level**

Capacity to Capture Market Share

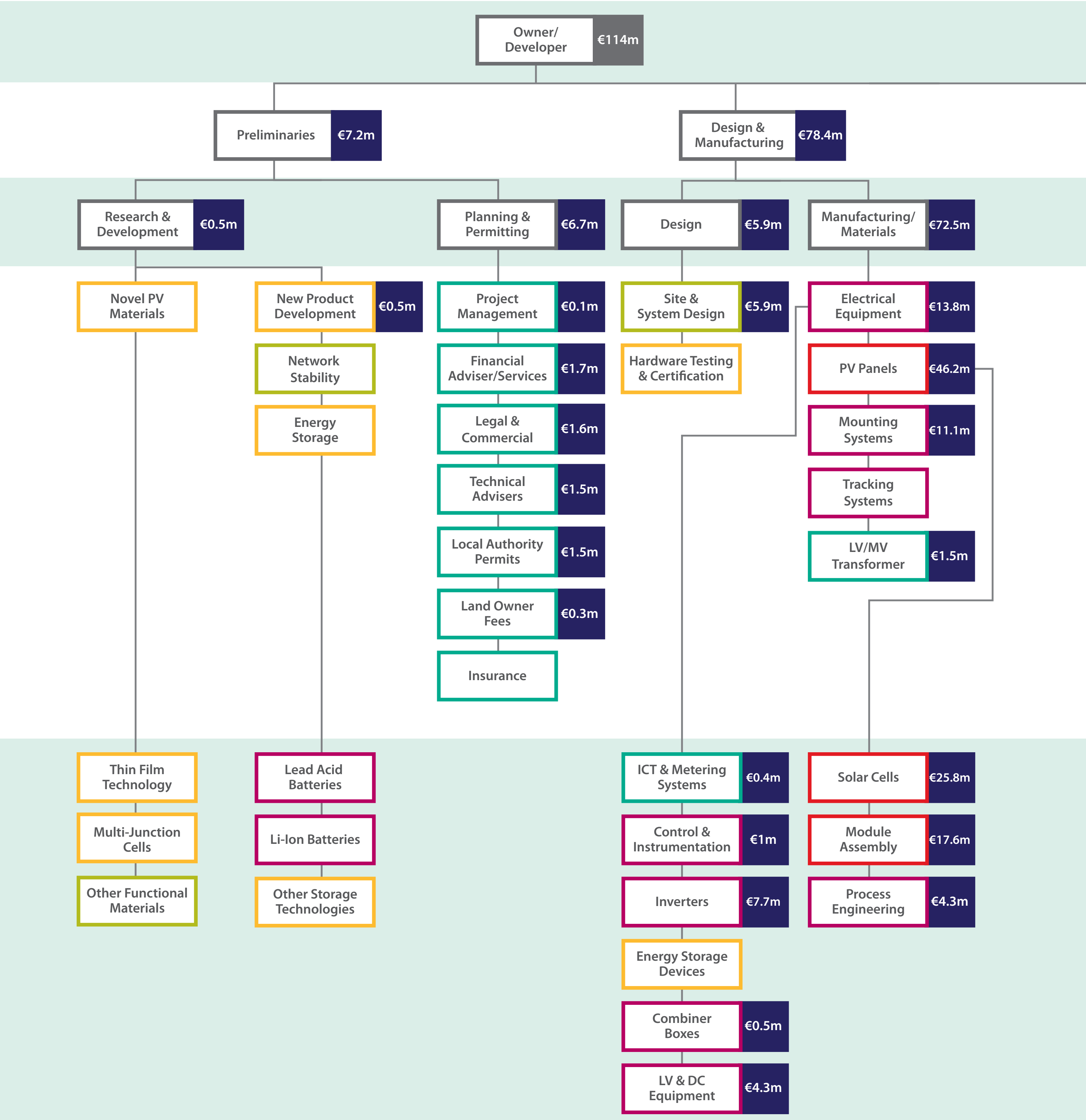
- Very well positioned
- Well positioned
- Averagely positioned
- Less well positioned
- Not well positioned



Appendix A (contd.)

Ground Mount Solar PV (Irish Market Value Breakdown €m/yr)

A.4: Expenditure in 2030 across the value chain due to investment in ground mount Solar PV systems in Ireland under the hi-RenS. The figures at higher parts of the tree are the sum of the figures shown in the parts of the tree linked by lines to them. Development costs are in dark blue, O&M costs in light blue. The colours of the value centres in levels 4 and 5 indicate the capacity of Irish business and research to capture market share.

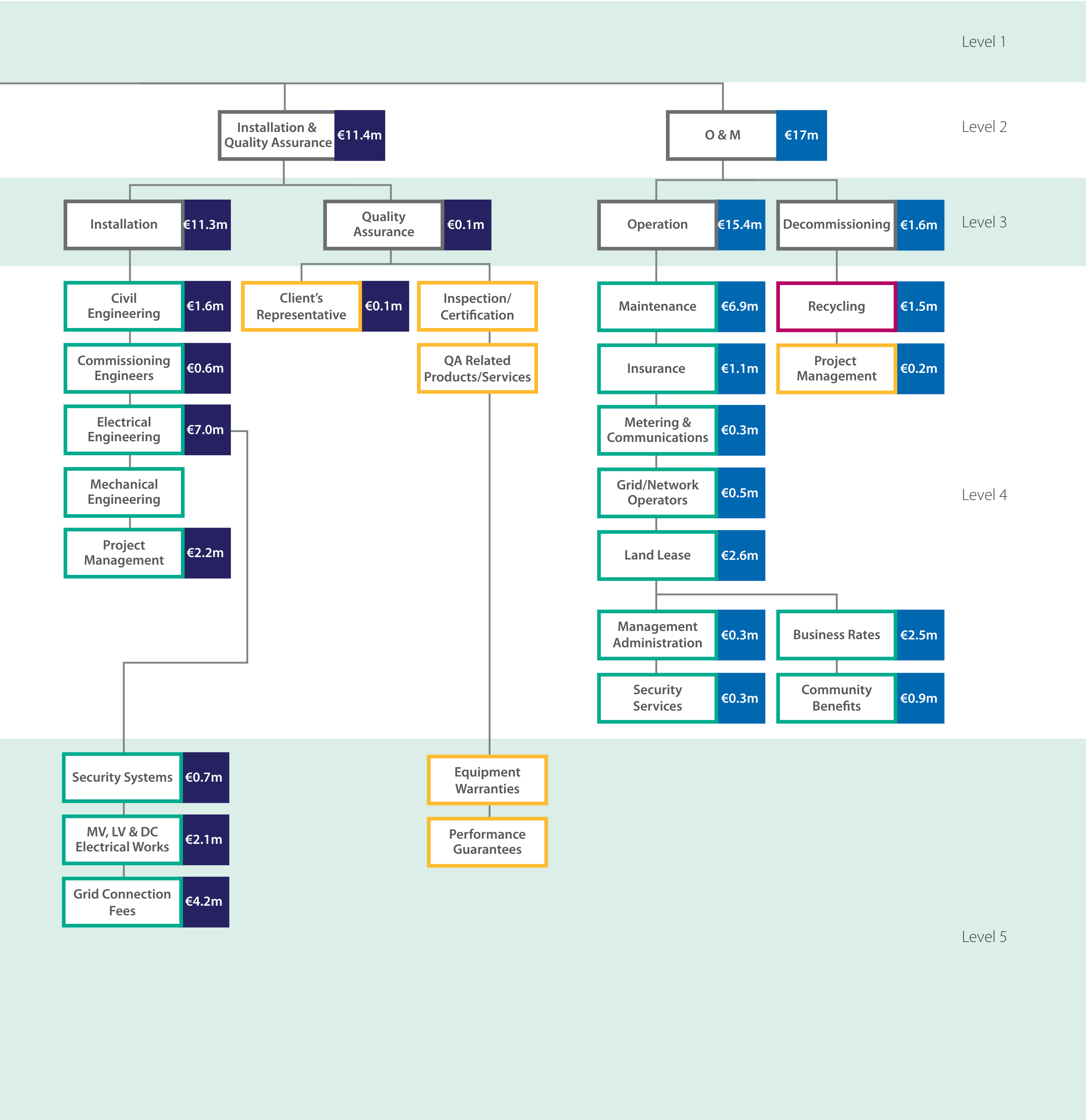


Value Chain Levels

Level 1 - **Ownership**
Level 2 - **Project**
Level 3 - **Lifecycle**
Level 4 - **Key Products/Suppliers**
Level 5 - **Component Level**

Capacity to Capture Market Share

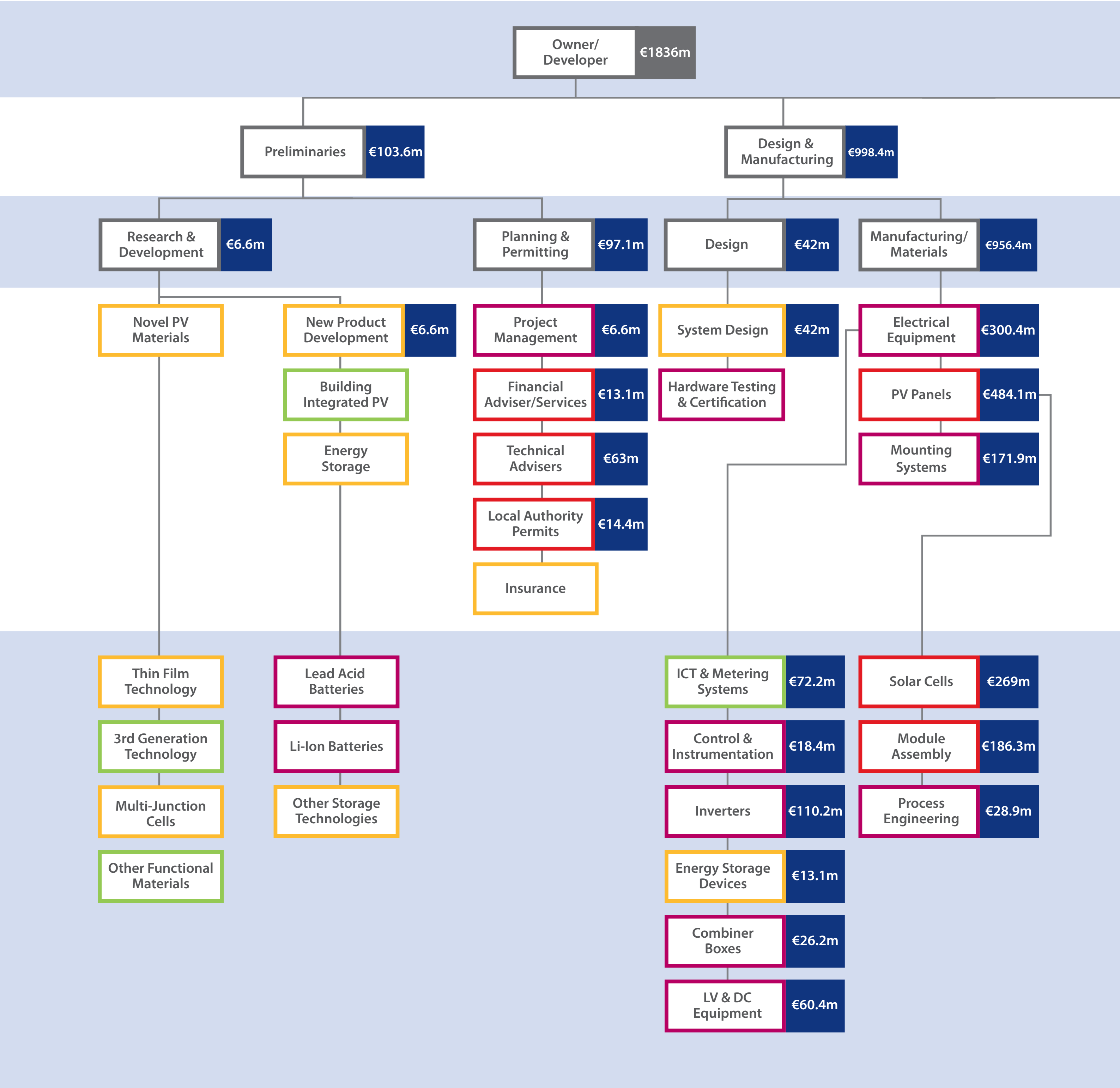
- Very well positioned
- Well positioned
- Averagely positioned
- Less well positioned
- Not well positioned



Appendix A (contd.)

Rooftop Solar PV (EU Market Value Breakdown €m/yr)

A.5: Expenditure in 2030 across the value chain due to investment in rooftop Solar PV systems in the EU (excl. Ireland) under the 6DS. The figures at higher parts of the tree are the sum of the figures shown in the parts of the tree linked by lines to them. Development costs are in dark blue, O&M costs in light blue. The colours of the value centres in levels 4 and 5 indicate the capacity of Irish business and research to capture market share.

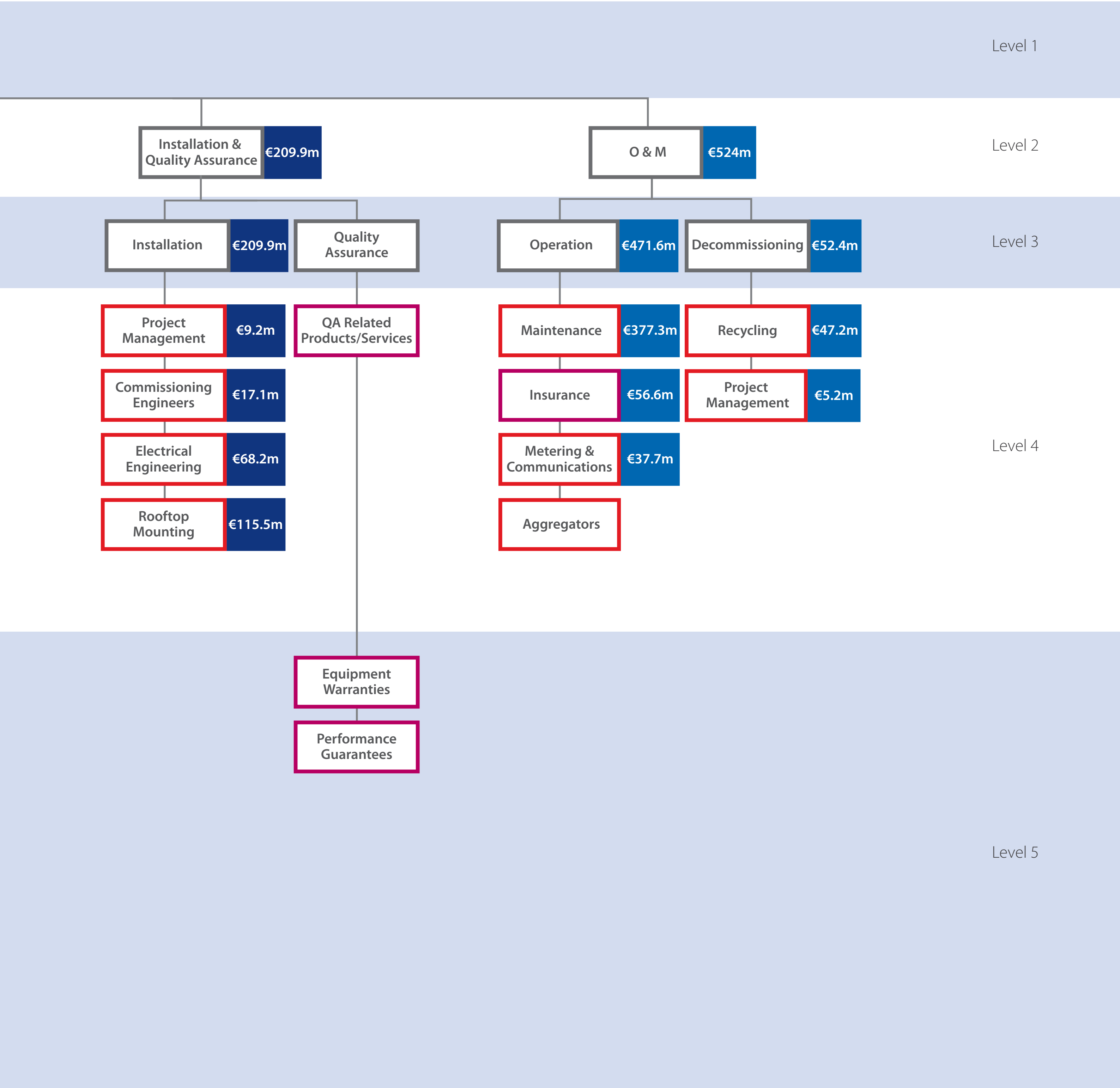


Value Chain Levels

Level 1 - **Ownership**
Level 2 - **Project**
Level 3 - **Lifecycle**
Level 4 - **Key Products/Suppliers**
Level 5 - **Component Level**

Capacity to Capture Market Share

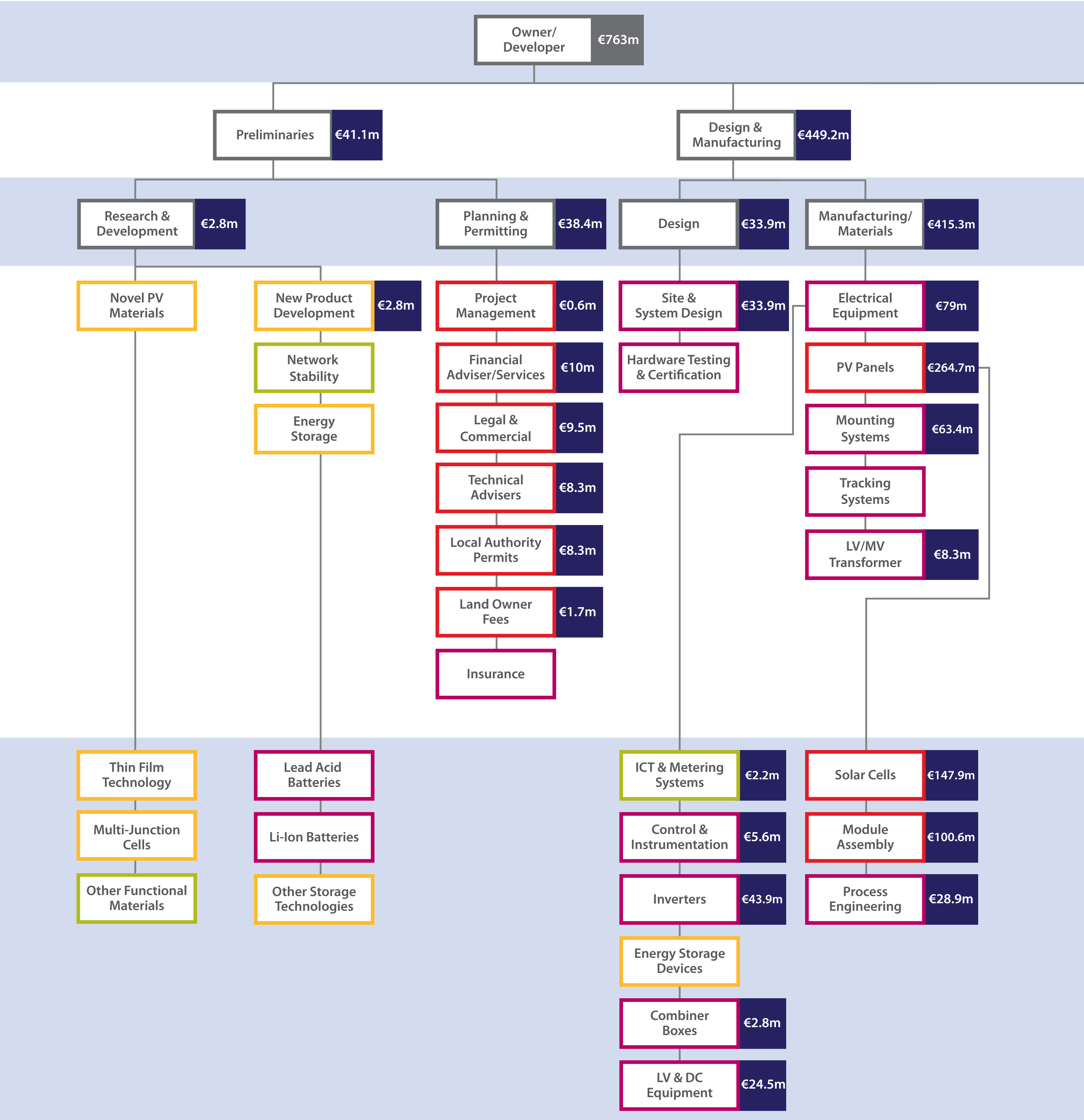
- Very well positioned
- Well positioned
- Averagely positioned
- Less well positioned
- Not well positioned



Appendix A (contd.)

Ground Mount Solar PV (EU Market Value Breakdown €m/yr)

A.6: Expenditure in 2030 across the value chain due to investment in ground mount Solar PV systems in the EU (excl. Ireland) under the 6DS. The figures at higher parts of the tree are the sum of the figures shown in the parts of the tree linked by lines to them. Development costs are in dark blue, O&M costs in light blue. The colours of the value centres in levels 4 and 5 indicate the capacity of Irish business and research to capture market share.

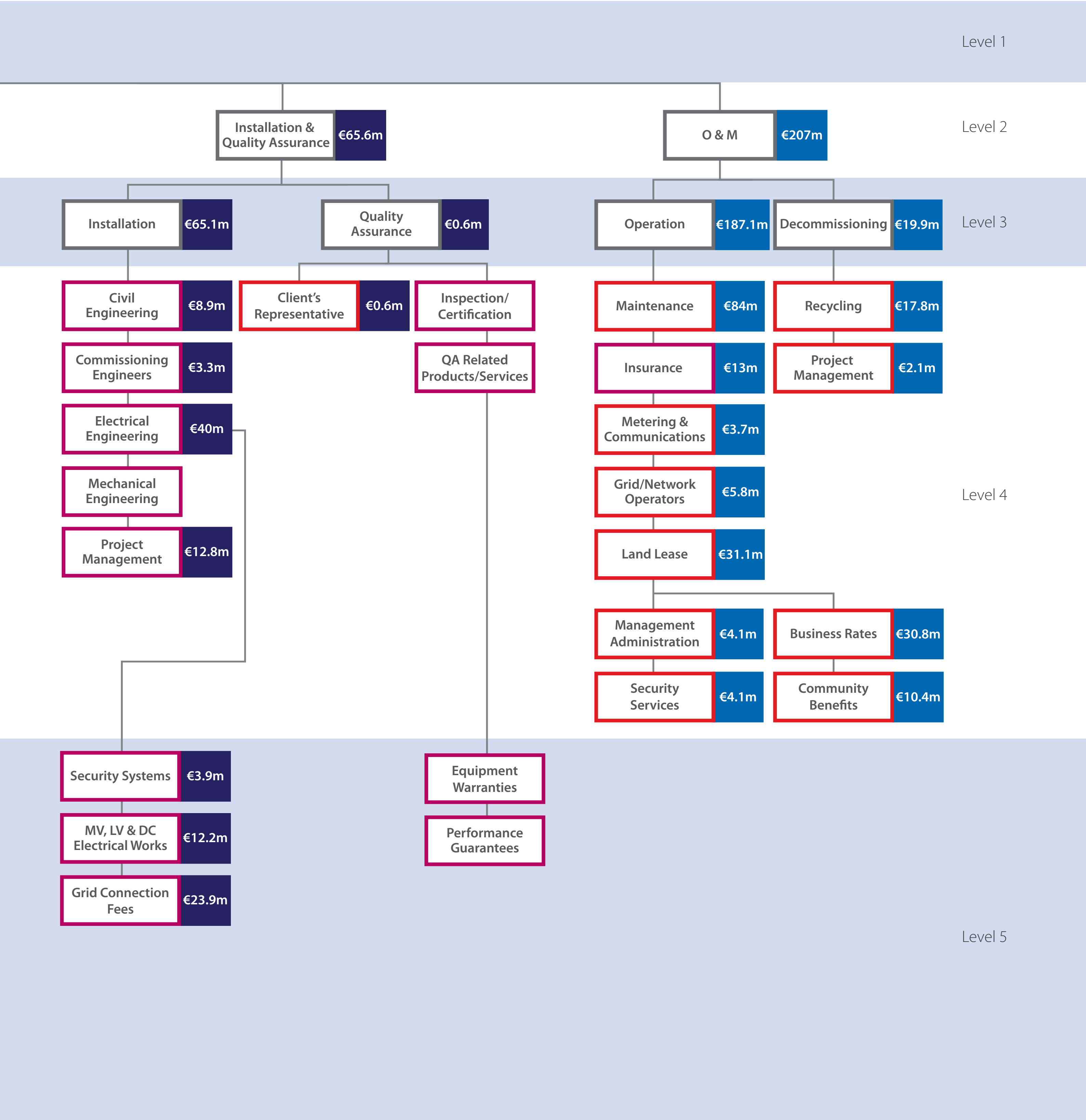


Value Chain Levels

Level 1 - **Ownership**
Level 2 - **Project**
Level 3 - **Lifecycle**
Level 4 - **Key Products/Suppliers**
Level 5 - **Component Level**

Capacity to Capture Market Share

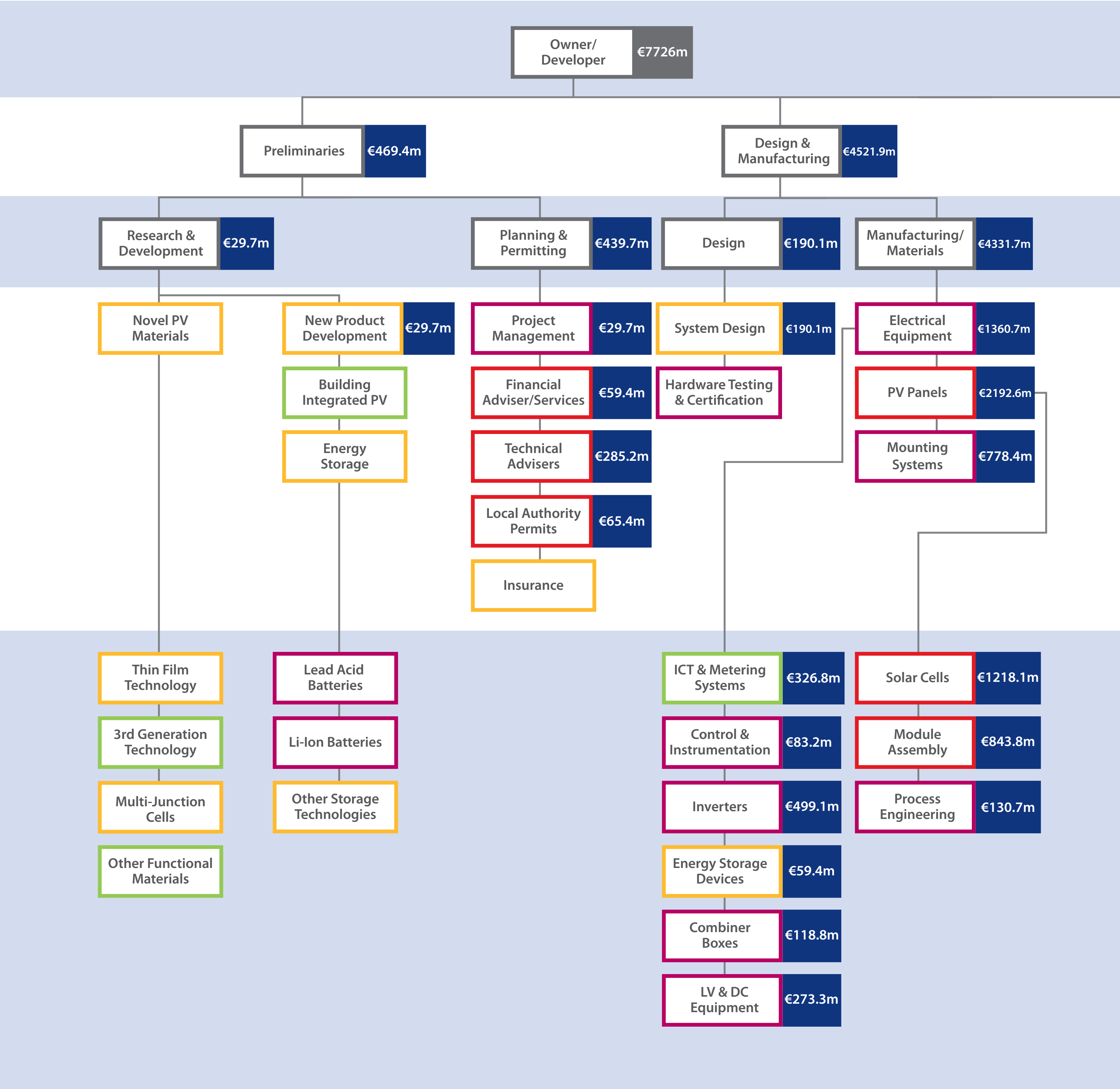
- Very well positioned
- Well positioned
- Averagely positioned
- Less well positioned
- Not well positioned



Appendix A (contd.)

Rooftop Solar PV (EU Market Value Breakdown €m/yr)

A.7: Expenditure in 2030 across the value chain due to investment in rooftop Solar PV systems in the EU (excl. Ireland) under the hi-RenS. The figures at higher parts of the tree are the sum of the figures shown in the parts of the tree linked by lines to them. Development costs are in dark blue, O&M costs in light blue. The colours of the value centres in levels 4 and 5 indicate the capacity of Irish business and research to capture market share.

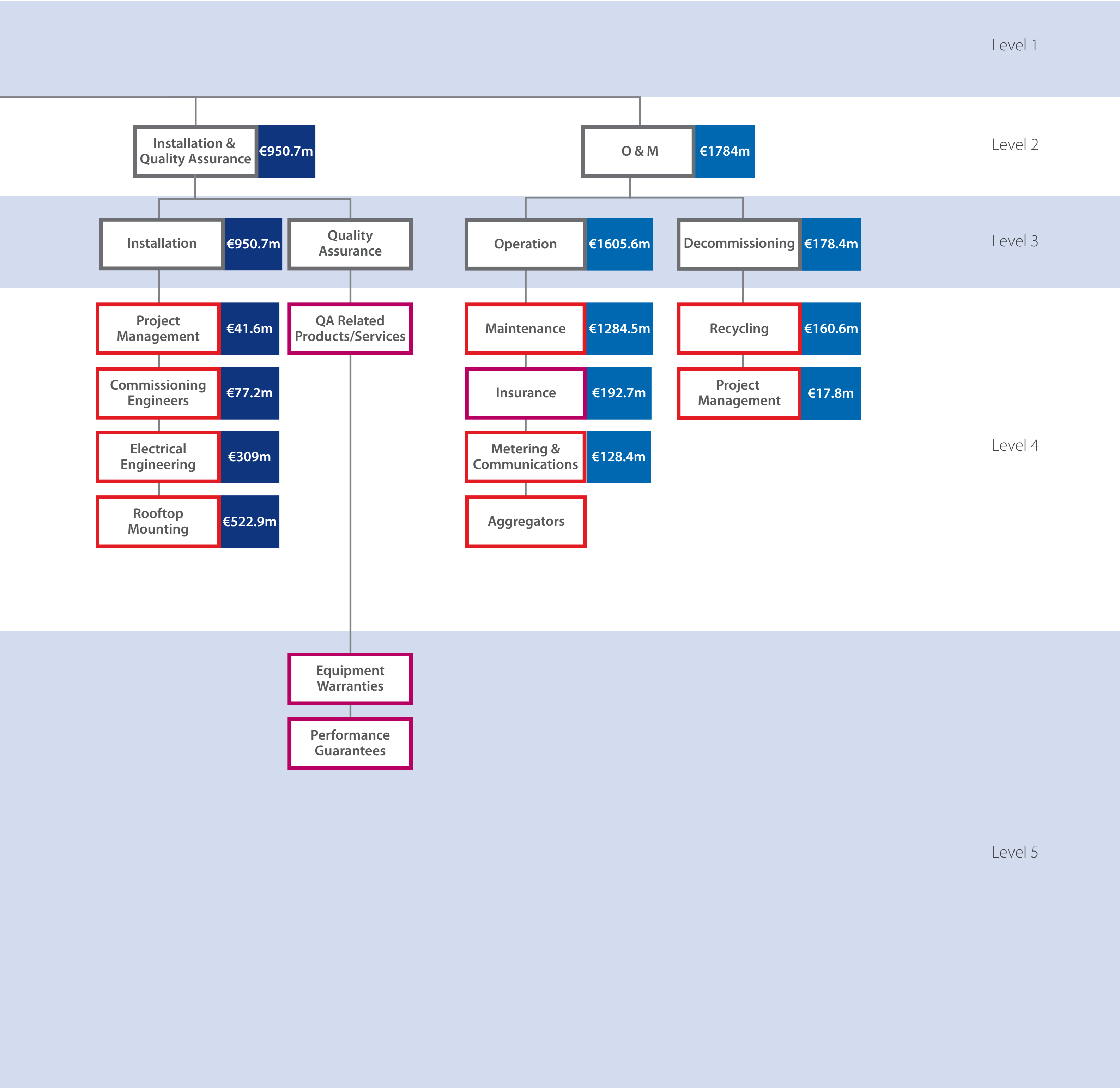


Value Chain Levels

Level 1 - Ownership
Level 2 - Project
Level 3 - Lifecycle
Level 4 - Key Products/Suppliers
Level 5 - Component Level

Capacity to Capture Market Share

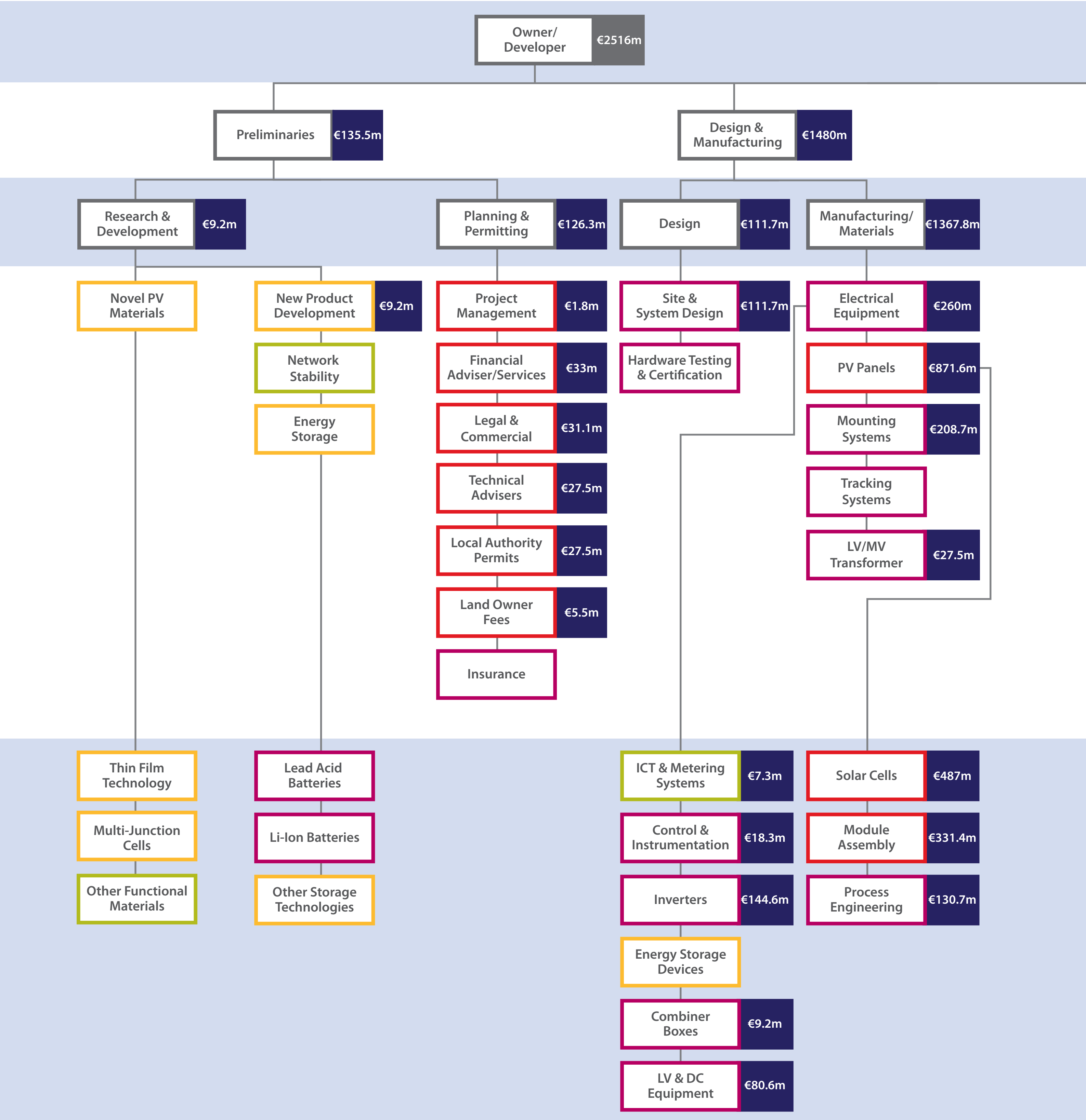
Very well positioned
Well positioned
Averagely positioned
Less well positioned
Not well positioned



Appendix A (contd.)

Ground Mount Solar PV (EU Market Value Breakdown €m/yr)

A.8: Expenditure in 2030 across the value chain due to investment in ground mount Solar PV systems in the EU (excl. Ireland) under the hi-RenS. The figures at higher parts of the tree are the sum of the figures shown in the parts of the tree linked by lines to them. Development costs are in dark blue, O&M costs in light blue. The colours of the value centres in levels 4 and 5 indicate the capacity of Irish business and research to capture market share.

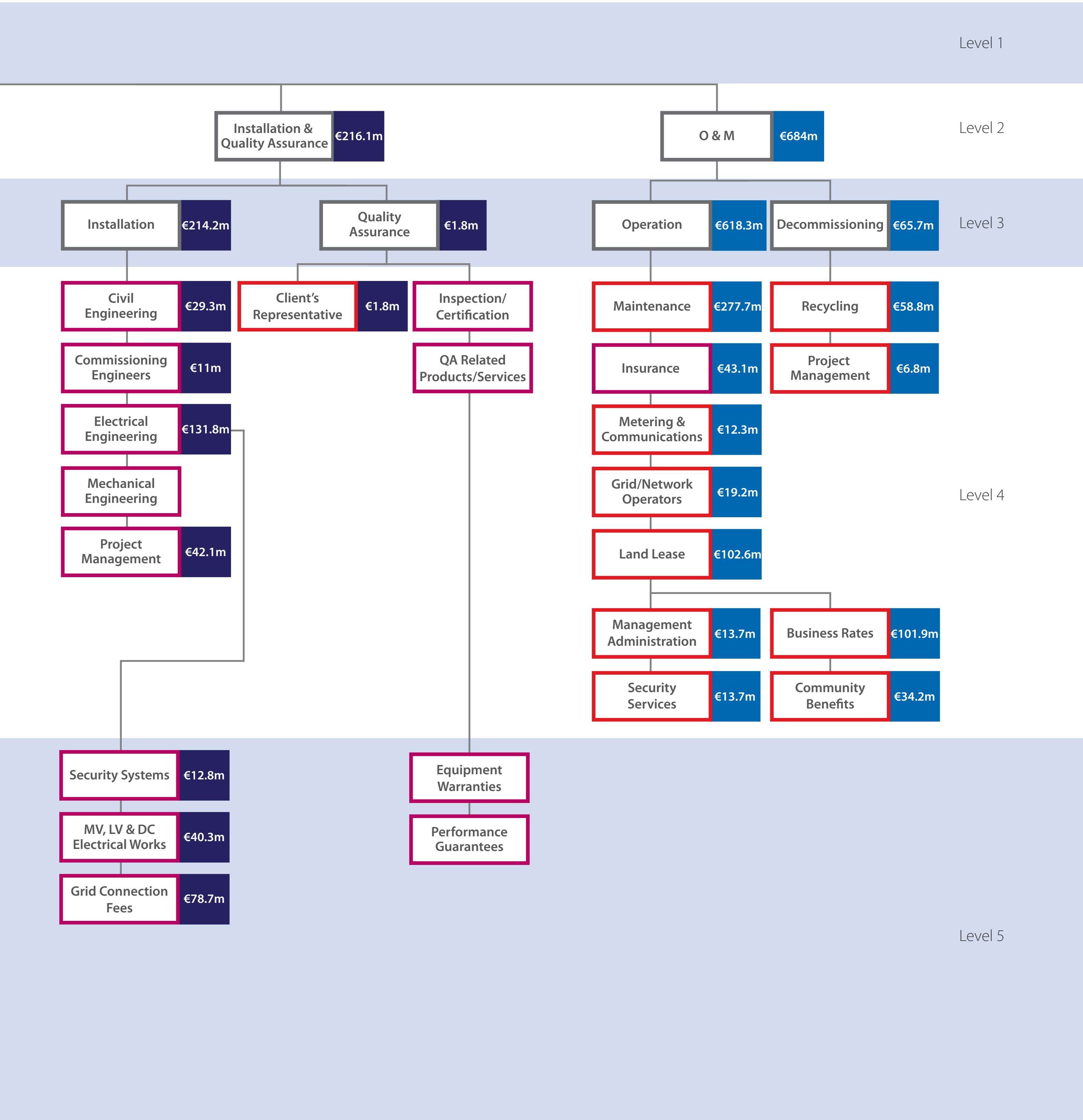


Value Chain Levels

Level 1 - Ownership
Level 2 - Project
Level 3 - Lifecycle
Level 4 - Key Products/Suppliers
Level 5 - Component Level

Capacity to Capture Market Share

Very well positioned
Well positioned
Averagely positioned
Less well positioned
Not well positioned



Appendix B

The literature review identified 36 sources that contained the type of cost data needed to develop the value chain analysis, including reports by consultants, public bodies and other institutions from Ireland, UK, EU and the USA.

Most of these reports considered only overall technology/project costs or were based on market research prior to 2010 and thus their data was only used in sense-checking the data from more recent/reliable sources. The remaining seven sources provided cost breakdown data used in our analysis of rooftop and ground mounted applications (see Table 6). The majority of sources provided data for 2015. Three main categories of cost information were extracted from the literature sources.

1. **Breakdowns of project development and installation costs**
2. **Breakdowns of operating and maintenance (O&M) costs**
3. **Typical annual O&M costs as a percentage of initial capital cost**

Table 6: *Sources of cost breakdown data*

TITLE OF SOURCE (E.G. REPORT)	ORGANISATION /AUTHOR	ROOFTOP	GROUND MOUNTED
A Brighter Future: The Potential Benefits of solar PV in Ireland (2015)	KPMG (Ireland)	X	X
Utility-Scale Solar Photovoltaic (2015)	International Finance Corporation (World Bank)		X
Cost reduction potential of large scale solar PV: an analysis into the potential cost reductions that the UK solar industry could deliver to 2030 with stable policy support (2014)	Solar Trade Association (UK)		X
Technology Innovation Needs Assessment (TINA): Solar Photovoltaic and Thermal Technologies Summary Report (2016)	Low carbon innovation coordination group (UK)	X	
Current and Future Cost of Photovoltaics Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems (2015)	Fraunhofer ISE (Germany)		X
U.S. Photovoltaic Prices and Cost Breakdowns: Q1 2015 Benchmarks for Residential, Commercial, and Utility-Scale Systems (2015)	NREL (USA)	X	X
Response to the Renewable Electricity Support Scheme Technology Review, DCENR (2016)	Irish Solar Energy Association		X
Addressing Solar Photovoltaic Operations and Maintenance Challenges: A Survey of Current Knowledge and Practices (2010)	EPRI (USA)		X
Decommissioning Statement (2012)	Camborne Energy (UK)		X
Solar Photovoltaics: An overview of European research and policy (2014)	EKRC (European Commission)	*	*

** R&D expenditure of companies only (not differentiated by application)*

Appendix C

Stakeholders Consulted: SEAI is grateful to the following stakeholders for their input:

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