The political economy of research and innovation in organic photovoltaics (OPV) in different world regions

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The Political Economy of Research and Innovation in Organic Photovoltaics (OPV) in Different World Regions[1]

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Abstract

Purpose: In this paper, we examine the status, prospects and organization of OPV research, innovation and governance in three major world regions: Northern America, Western Europe and East Asia through our constructed evolutionary cognitive-institutional framework of reference. **Method:** We gathered data from a 65-question internet-based survey conducted from February 2013 to April 2013 with OPV researchers and research managers around the world. A multi-method (investigative/exploratory, descriptive statistics) approach is used for analyses and discussions. **Results:** Overall findings show that the organization of OPV research, innovation and governance in Northern America, Western Europe and East Asia reflect similar aspects, patterns with their political economies surveyed in the literature: Northern America's neo-liberal market and finance orientation, Western Europe's orientation to sustainable development and policy-driven research, coordinated-regulatory inspirations and research-driven system, and East Asia's neo-developmental state view with international trade, technology-export orientation. Commercialization prospects in China are lowest and highest in the US but even there expectations of market sales are low. As a disruptive technology which is competing with older generations of PV and other energy technologies, OPV requires a coordinated effort involving international cooperation, the use of public and private money. Positive elements of the three world regions (availability of venture capital in the US, the meritocratic research system and ambitious goals for renewable energy in the EU, and the willingness of the Chinese government to back sunrise industries) could be usefully exploited.

Keywords: Political Economy, Emerging Energy Technology, Research, Innovation, Governance, Organic Photovoltaics

JEL Classification: P16, P51, O38, Q55

1. Introduction

Solar photovoltaics technology is based on conversion of sunlight into electricity at the atomic level. In comparison to other renewable energy technologies such as wind, hydro, geothermal energy technologies, solar photovoltaics technology is the only truly portable renewable energy technology (Brabec, 2004). Classical photovoltaics use polysilicon as raw material and semiconductor processing technologies to produce crystalline solar cells/modules. Organic photovoltaics technology, as a next generation solar technology, introduces organic photovoltaic elements as absorbers, alternative contact materials to replace polysilicon. These features affect characteristics and manufacturing processes of solar cells. The use of organic materials brings

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flexibility and semi-transparency to photovoltaics cells which can be manufactured in a continuous printing process, packaged by lamination techniques. For the time being, Organic Solar PV is an emerging energy technology.

The interest in OPV is driven by unique features of OPV cells: *"The promise of organic photovoltaics is an ultra-low-cost technology that could be fabricated in a continuous process and implemented on flexible substrates. Its manufacture may be similar to, but inherently simpler than, conventional color-film production. The challenge of OPV is to increase the efficiency and reliability"* (NREL, 2007).[2]

OPV has come into the international research focus after 2001 as one of the future key technologies that opened up possibilities for completely new applications and markets for photovoltaics such as large area-coating, integration with different portable consumer electronics, textiles, and many other niche applications. According to Spanggaard and Krebs (2004), there are also substantial ecological and economic advantages of OPV technology. However, improvements in efficiency, lifetime and costs are needed to capture a sizable part of the market. Brabec (2004) states that*"…organic solar cells have to fulfill all requirements (efficiency, lifetime and cost) simultaneously otherwise they will be limited to a niche market."* In order to fulfill these three criteria, scientific and technological research in the field of OPV focus on efficiency and lifetime by activities such as improving and optimizing absorbers, multi-junction architectures, encapsulation, alternative contact materials in order to reduce cell degradation and push cell lifetimes to industry-relevant values. The U.S. Department of Energy (DoE) indicates that *"…OPV technology has the theoretical potential to provide less expensive energy than first- and second-generation solar technologies…"* and states that *"DoE funds research and development projects related to organic photovoltaics (OPV) due to the unique benefits it offers"*[3].

In terms of its market, "Organic Photovoltaics (OPV) 2012-2022: Technologies, Markets, Players Report" of IDTechEx by Dr. Khasha Ghaffarzadeh, Dr. Harry Zervos and Raghu Das estimates that *"the organic photovoltaics (OPV) market today is $4.6 million"* and forecast that *"it will rise to USD630 million in 2022"*. The report adds that *"The market growth will be predominantly driven by electronics in apparel, posters and PoP smart labels, and off-grid developing world applications and OPVs will nonetheless remain a small player on the greater PV scene, obtaining total market shares, <1.5 percent"* (Business Wire, June 14, 2012, pg.1). Another report titled "Organic Photovoltaics (OPVs) 2013" by SNE Research states that *"OPVs are expected to enter the full-scale mass-production stage in 2014 with production of 28MW, and continue to grow rapidly, reaching 94MW in 2015 and more than 1GW in 2020"* (Business Wire, September 25, 2013, pg.1). However, all numbers are corrected downwards in a current report: according to the latest IDTechEx Research report "'Organic Photovoltaics (OPV) 2013-2023:

[2] http://www1.eere.energy.gov/solar/pdfs/41738.pdf

[3] http://www1.eere.energy.gov/solar/sunshot/pv_organic.html

Technologies, Markets, Players Report "…*the overall value is expected to remain smaller than USD87 million in 2023 and the total installed capacity in 2023 at <74 MW. These are not large values considering that the total installed PV capacity in 2011 was 23-24 GW. Therefore, organic PV will remain a small market with approximately one% total market share''* (Business Wire, May 3, 2013, pg.1).

Considering that the OPV is such an interesting emerging energy technology, in this article, we aim to examine the status, prospects and organization of OPV research, innovation and governance for this third generation, Organic Photovoltaic (OPV) technology in detail at global aggregate level and in three major world regions; namely Northern America, Western Europe and East Asia. Section 2 provides theoretical and empirical background of our political economy and systems of innovation co-framework. Section 3 gives information on the global OPV survey that we developed and conducted from February 2013 to April 2013, and other data sources, methodologies used in our study. Section 4 provides empirical findings, reviews and preliminary discussions. Section 5 investigates the political economy aspects of the organization of research, innovation and governance in these major world regions in the scene of OPV. Section 6 investigates benefits from international cooperation through an exploitation of the three regimes for OPV research and innovation.

2. Theoretical Background

In this article we are interested in the political economy of research and innovation in the field OPV: the degree of government funding (from national and local authorities), the role that scientific excellence and industrial needs play in OPV research, the conflicts of interest among OPV researchers, the funding levels and the degree to which funding is viewed as adequate by researchers, and the market prospects for OPV applications in the different part of the world and the systems of innovation elements behind this.

OPV is a potentially disruptive technology which requires coordination from different actors over a sustained period to come to fruition but attempts at that are hindered by market realities (the competition from crystalline PV), demand from non-OPV researchers for research money and what has been called a waiting game among investors (Parandian, 2011). OPV does have a constituency of its own which includes market analysts and researchers. In OPV market assessments, the following range of market segments, have been assessed as areas for OPV use: *"automotive, posters and point-of-purchase (PoP) advertisements, apparel (clothes, sportswear, military uniforms, etc.), customer electronics (e-readers, mobile phones, watches, toys, etc.), off-grid applications for the developing world, power generation, and building integrated photovoltaics*" (Business Wire, May 3, 2013, pg.1). As a technology OPV is different than classical photovoltaics. Use of organic elements is behind this difference. Scharber and Sariciftci (2013) lists impacts of this difference as *"low weight and flexibility of the PV modules; semi-transparency; easy integration into other product; new market opportunities, e.g. wearable PV; significantly lower manufacturing costs compared to conventional inorganic technologies;*

manufacturing of OPV in a continuous process using state of the art printing tools; short energy payback times and low environmental impact during manufacturing and operations." Scharber and Sariciftci (2013) conclude that these features are of the advantages each of which suggests that OPV does have the potential to be a disruptive technology within the PV market. OPV is indeed a discontinuous innovation which may make obsolete past investments and competences but which necessitates the creation of new networks, involving powerful actors, clever combinations with other technologies and the targeting of niche markets Birkinshaw et al. (2007). OPV is very much driven by promises made by scientists and researchers. In the political economy and political science literature there is a long discussion about whether policy is determined by interests and ideas, beliefs. We take the view that the two are not really separable from each other. According to John (1999), interests, in the first-order, *"are the benefits (material gain, fame, power) which individual agents gain from following a course of action or inaction"*. However, *"in order to connect the first-order interests to the second-order interests (preferred ways to reach the first-order interest)* every agents need to have a set of ideas. Ideas, in the first-order are policy proposals which are relatively discrete packages of measures that are capable of being selected as policies and at second-order level, they are of *"systems of ideas or ideologies which connect to and influence policy proposals"* (John, 1999).

In an emerging technology phase, the overall role (interests, ideas, rules and play) of firms and industry can be expected to be embryonic, with an important role for universities, research institutes and funding agencies. The research agenda is driven by ideas of what is scientifically and technologically possible and feasible, but also by business needs and sustainability concerns as well. Research and innovation policy is not a simple matter of interests. Menendez and Borras (2010) state that "*public action depends on the preferences of decision makers, and preferences are not the simple expression of actors' interests but ideas are of relevance"*. Accordingly, conceptualizing institutions as sites emerged from aggregated firm-level choices and/or as sites for the exercise of power (with respect to reproduction or transformation of firm choices, industrial behaviour, thus, routinized behaviours through constraining or fostering interventions) actually make a statement on what governments or firms, state and market can or cannot accomplish alone (Hall and Soskice, 2001; Peck and Theodore, 2007).

In the case of research and innovation policy, research ideas of what it possible and worthwhile play an important role in funding. Such ideas may derive from scientists, but they are subjected to selection mechanisms in science (peer reviews in which scientific novelty and the reputation of the scientists are key evaluation criteria), and (mostly indirect) evaluation by policy makers and business. For promising technologies, special programmes get created on the basis of claims of societal benefits, something which holds true for OPV. Over and above this, we have the creation of local and global networks of scientists and researchers. These networks may be purely scientific networks but there are also networks which involve business and innovation branches of government. The networks are set up to facilitate learning but they are also fora for furthering individual interests. Therefore, in our survey we analyse the nature and nurture of engagement of

researchers, firms, universities, governments at different levels, international cooperation and market orientation in organization of OPV research, innovation and governance.

The interplay of ideas and interests in visible in a case reported in Business Wire: *"As part of his first official tour of Saxony, German Federal President Joachim Gauck called in at the TU Dresden (Technical University of Dresden) where he met the team of scientists who founded Novaled and who won the President's award for technology and innovation - the Deutscher Zukunftspreis (German Future Prize). The scientists were honored for the outstanding results of their research into organic semiconductors and for the successful commercial exploitation of their findings."* According to the news, Dr. Blochwitz-Nimoth, Chief Scientific Officer at Novaled says *"At the beginning there was an idea, a vision, for which we were deemed crazy by a lot of people. Today, the rise of organic electronics cannot be stopped."* and adds *"the interest shown by President Gauck indicates the high value he attaches to pioneering research and to its economic exploitation for Germany*" (Business Wire, April, 30, 2013, pg.1).

In Germany, the Federal Ministry of Education and Research (BMBF) decided to fund a national partnership *"to achieve a breakthrough in organic photovoltaics (OPV) leading to commercialization. The partnership, consists of Merck AG, Siemens AG, the Center for Applied Energy Systems (Erlangen), PolyIC GmbH & Co. KG, the Karlsruhe Institute of Technology, the Leonard Kurz foundation (Furth), Belectric OPV GmbH, CentroSolar Glas GmbH & Co. KG and the Center for Solar Energy and Hydrogen Research (Stuttgart) and Webasto"* (ENP Newswire, November 27, 2013, pg.1). When all actors are national, and involve business in an important way, there usually is an industrial policy aim behind the arrangement.

Another example of a partnership between researchers, government and business is the Victorian Organic Solar Cell Consortium consisting of CSIRO (National Science Agency of Australia), The University of Melbourne, Monash University, BlueScope Steel, Robert Bosch SEA (regional subsidiary of the Bosch Group/Germany), Innovia Films and Innovia Security (Britain) and the consortium is supported by the Victorian State Government and the Australian Government (multi-level) through the Australian Renewable Energy Agency (Clean Technica, May 19, 2013, pg.1). It is also example of an international, multi-level and multi-organizational type partnership.

In this paper we use the notion of *systems of research and innovation* for OPV as a theoretical organizer, as a hybrid system of innovation framework, which assumes that *innovation institutions are embedded in a much wider socio-economic system in which political and cultural influences as well as economic policies help to determine the scale, direction and relative success of all innovative activities* (Freeman 2002: 194). *Our framework supersedes the* technological systems of innovation framework for emerging technologies (Carlsson and Stankiewicz, 1991; Carlsson 1997) for the reason that OPV activities are not only technological but also occur within wider frameworks whose features shape the activities and outcomes. These frameworks are regional, national systems of innovation (Cooke, 2010; Freeman and Soete, 1997) and the sectoral systems of innovation (Breschi and Malerba, 1997), the details of which are described in

Table 1, together with the way in which they are used. Our approach builds on and extents the socio-technical systems approach through the attention to different political economies, varieties of capitalism as macro-economic institutions shaping OPV research, innovation and governance.

Table 1- The Systems of Innovation Frameworks

Concept/Construct	Literature	Survey Design	Selected Questions of our OPV Survey
Technological Systems of Innovation	Carlsson and Stankiewicz (1991)	Micro-level (individual expertise, organizational (research) excellence)	Excellence with respect to Field and Type of Research; Licensing/Patenting/Spin-offs; Barriers to Commercialization…
Regional System of Innovation	Cooke (2010)	Meso-level (regional (sub-national network))	Company involvement/ Regional (Sub-national) Networking for OPV; Degree of Local Authorities Involvement in Partnerships; Policy Coordination between regional and national level…
National System of Innovation	Freeman and Soete (1997)	Macro-level (policy and programmes, international cooperation)	Conflicts of Interest, National Platform; Level of Public Funding; National Programmes; Political/ Government Missions…
Sectoral System of Innovation	Breschi and Malerba (1997)	Crosscutting technology-level (type of research, field of research and commercialization prospects)	Cost improvements in Crystalline Si and Thin Film; Support spread, portfolio broadness; What role do industrial needs play in OPV Research? (%); Short-term industrial needs in determining OPV Research Agenda…
Socio-technical System of Innovation	Geels (2004)	Links between (e.g. programmes and commercialization)	How important is commercialization of OPV in Support programmes; Success factors for Commercialization; First-market Applications…

The varieties of capitalism scheme holds that world regions are characterized by different cognitive-institutional frameworks such as liberal-market economy (LME - Anglo-American variety), coordinated-market economy (CME - Continental European variety), East Asian developmental state capitalism (for a review of this typology and others see Rodrigues, 2010; Amable, 2003; Chang, 2002; Block and Keller, 2000; Williamson, 1990; 2004; Ozis 1991). One goal of the paper is to investigate whether the governance system for research and innovation in OPV fits with the varieties of capitalism in the three foremost world regions: North America, Western Europe and East Asia.

Table 2- Characteristics of Varieties of Capitalism

	LME (USA and Britain)	CME	East Asian Developmental State
Business-to-business coordination	Low	High	High (within conglomerates)
Industrial policy	Low	Low	High (picks winners)
Bureaucracy	Partially meritocratic, somewhat politicized, technocratic	Partially meritocratic, somewhat politicized, technocratic	Meritocratic and technocratic
Industrial relations	Moderate training and labor collective bargaining	Extensive skills training and labor collective bargaining	Extensive in-firm training support, wage negotiation mitigated by life-time employment
Labor	Independent and moderate but declining	Corporatist, independent and strong	Incorporated, Firm-based, weak
Finance and debt (relative to GDP)	Low FDI Moderate debt	Low FDI Moderate debt	Low FDI Internal subsidies High Debt
Research and development	Combination of government, academia, and business	Government and EU funded. Private sector involvement	Government supported
Skills development	Weak vocational. Strong tertiary. Little government involvement	Guilds, Apprentice-ships, Strong vocational.	Strong vocational, life-time employment (falling) government /private partnership
Society/welfare	Moderate public and private funded	Extensive publicly funded	Limited but public-funded

Source: Adapted from Ritchie (2009) that surveys Johnson, 1982; Amsden, 1989; Deyo, 1989; Wade, 1990; Doner et al. 2005; Hall and Soskice, 2001; Huber, 2002; Pempel,2002

For the different world regions we examine the i) characteristics of diversity creation mechanisms in OPV research and development, ii) the influence of business, government and academic merit as determinants of OPV research and innovation, iii) the degree of policy coordination and fragmentation, iv) the role that prospects of commercialization play in funding decisions and in motivating research, and v) strategies used to appropriate the benefits from innovation through patents.

3. Data, Measures and Methodology

In this paper, we use two data sources. The first one is the 65-question survey which we designed to systematically survey the status, prospects, and organization of research, innovation and governance in the field of OPV as a whole yet in details. The sections of the OPV Surveys are of micro-level (individual expertise, organizational (research) excellence), meso-level (regional (sub-national network)), macro-level (policy and programmes, international cooperation), crosscutting technology-level (type of research, field of research and commercialization prospects), and links between (e.g. programmes for commercialization). In the Table 1 and Table 2 above, we presented the theoretical background of these listed aspects. The questions are fact

(experience) and opinion/perception-based. Our statements in the OPV Survey are not hypotheses but are a heuristic to inquire into beliefs. They are not expected to be true, but refer to a relevant cognitive-institutional political economy component of the organization of research and innovation system. From February 2013 to April 2013, 107 experts worldwide who published in peer-reviewed indexed journals in the field of OPV responded to our internet-based survey. 73 experts are conducting research in major world regions. The breakdown is North America 19; Western Europe, 27; and East Asia, 26 experts. The small sample size means that local/regional and country level differences could not be studied, which limits our study to aggregate (major world regions) level. At local/regional and national level, deeper analyses of policy beliefs and institutional arrangements around OPV could shed further light onto the constituents of cognitive-institutional political economy components underlying the organization of research and innovation system. For studying beliefs, we asked OPV researchers/research project managers to indicate their agreement and disagreement with statements for evaluating the research and innovation system for OPV, thus, we are limited to this sub-sample of actors (researchers/scientific project managers among other experts from business firms, government officials, intermediaries, or end-users) in the OPV scene. Therefore, the data on the policy beliefs, industrial alignments and institutional arrangements is gathered from the perspectives of this sub-group/sample. Although our email list covered all actors in the OPV from universities, research centres, government institutes, companies who have published articles in indexed journals such as SCI, we could not receive responses from business firms and government officials. Of the different groups, researchers/scientific project and research managers can be expected to be most knowledgeable about the funding systems and the influence of different groups on OPV research. The approach taken also has the advantage of capturing the diversity of OPV research and funding. However, deeper and more inclusive (business firms, government officials, intermediaries, end-users) analysis of institutional arrangements around OPV and policy beliefs could shed more light onto the topic of inquiry although it is difficult to accomplish this task for either world regions or local/regional levels. Diversity in the answers tells us something about the extent to which beliefs vary. We collected news articles from Lexis Nexis Academic to provide empirical background and to extend preliminary discussions to everyday events in the field of OPV. Multi-method (investigative/exploratory, descriptive statistics) approach is used for analyses and discussions. Appendix A covers the statistical profile of the respondents.

4. Empirical Results

4.1. Company involvement/ Regional (Sub-national) Networking for OPV

In the figures below we first analyse the company involvement in OPV Research. Globally (72.9%) of regional networks involve companies in the field of OPV. However, only 14% of the respondents indicate that companies are very actively involved in OPV Research. 38.3% reports that companies involved but not as much as research institutes.

Figure 1– Regional Network involving companies (Left) and Degree of Company Involvement (Right)

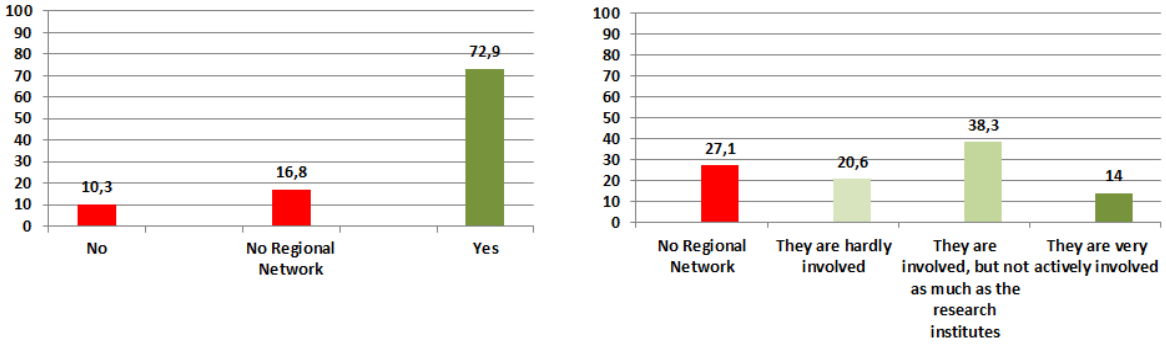
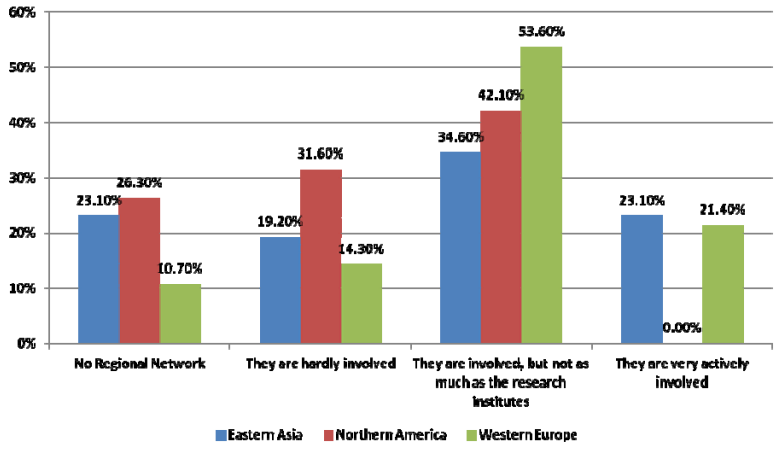
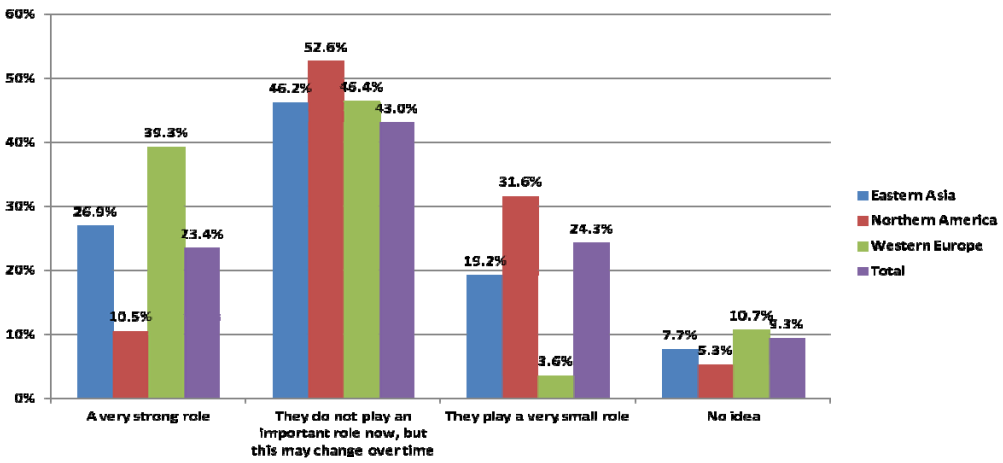


Figure 2– Degree of Company Involvement in Major World Regions



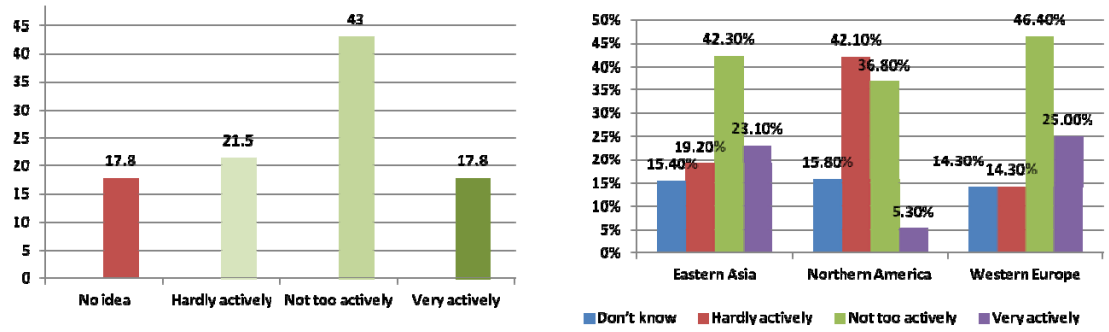
Active company involvement in research within regional networks is observed at similar levels in East Asia (23.1%) and Western Europe (21.4%). For all regions research institutes are more actively engaged in OPV than companies.

Figure 3 – What role do industrial needs play in OPV Research? (%)



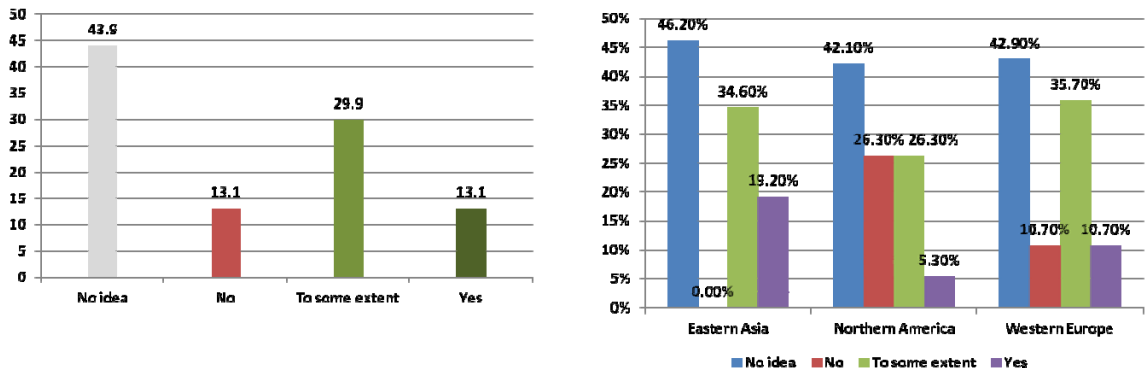
Industrial needs do not play an important role at the moment but respondents think that this may change over time (46.2-52.6%) in the three world regions. Industrial needs play the highest role in Western Europe, with 40% stating that they are important. After observing choice and behaviour of company and research organizations in OPV research at regional network level, we analyse the involvement level of local authorities in partnerships. Just like companies, local authorities are not "very actively involved" in the partnerships. Western Europe and East Asia have similar levels of very active involvement at ~23-25% level.

Figure 4– Degree of Local Authorities Involvement in Partnerships and Breakdown (%)



We also asked researchers about the involvement of OPV researchers in policy discussions. The results are given in Figure 6.

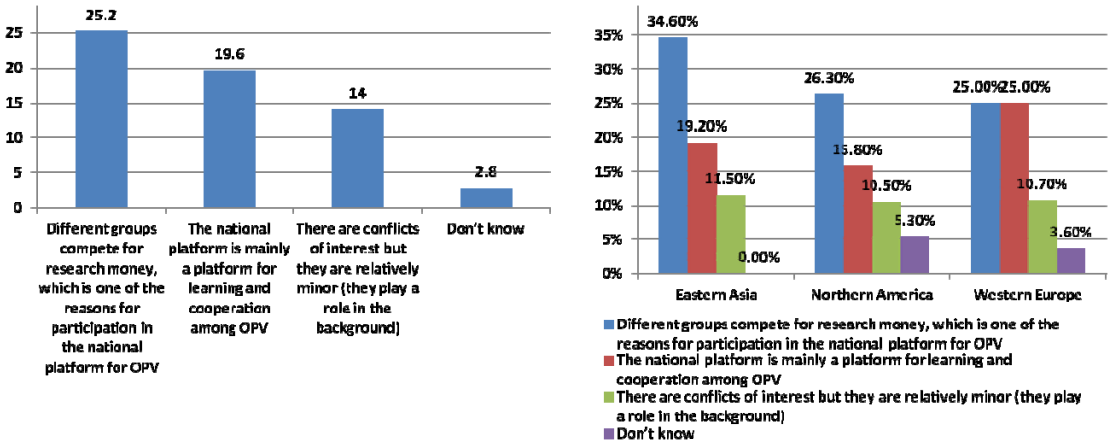
Figure 5– Involvement of Researchers in Policy Discussions (%)



Most researchers have no idea about the involvement of OPV network members in policy discussions. 29.9% state that OPV researchers are involved in policy discussions "to some extent" (29.9%) and 13.1 % answer the question with a clear "yes". East Asia has more active discussion of policy issues with local authorities (19.20%) but the share is still low. Most OPV researchers are part of some platform. The most important motivation for being in those platforms is to secure their interests as researchers. Learning from others is the second most important reason, mentioned by 19.6% of the respondents, which is more important than learning. 14% say that there are conflicts of interest but they play relatively minor role. About

these platforms we asked if not in regional level, we analyse at national level what role conflict of interests play.

Figure 6 – Conflicts of Interest, National Platform and Regional breakdown (%)

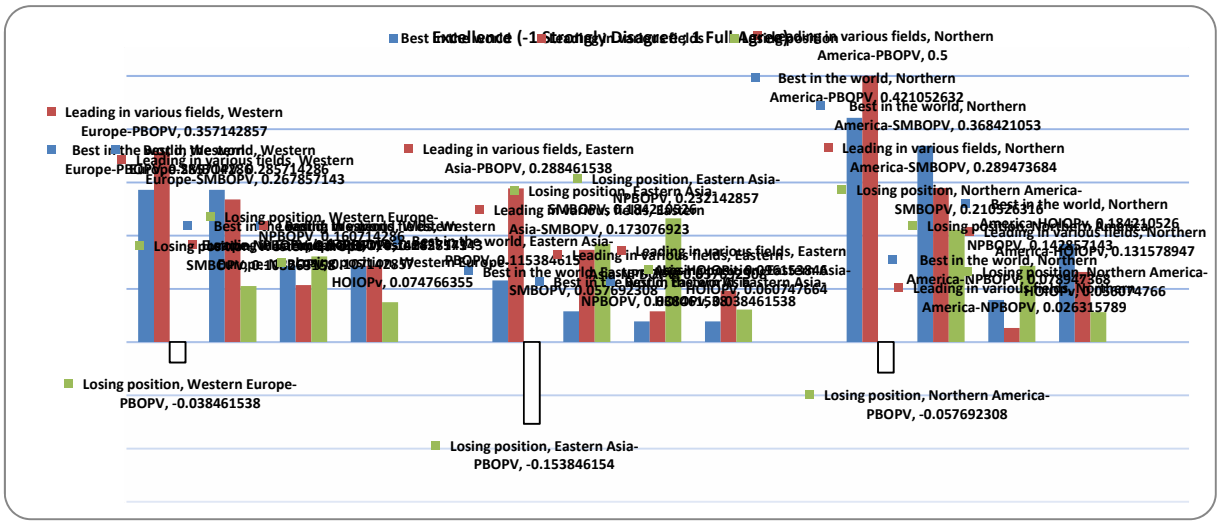


From the subgroup taking place in a national platform/network, for the 3 world regions we observe similar patterns. Competition for research money is the most important reason, followed by learning and cooperation. This finding led us to investigate if the portfolio of OPV research is too broad and if policy support is spread out over many technologies.

4.2 Organizational Excellence, Policy and Programmes for OPV

Figure below presents the status and position of research on different fields of OPV Research.

Figure 7- Excellence with respect to Field and Type of Research

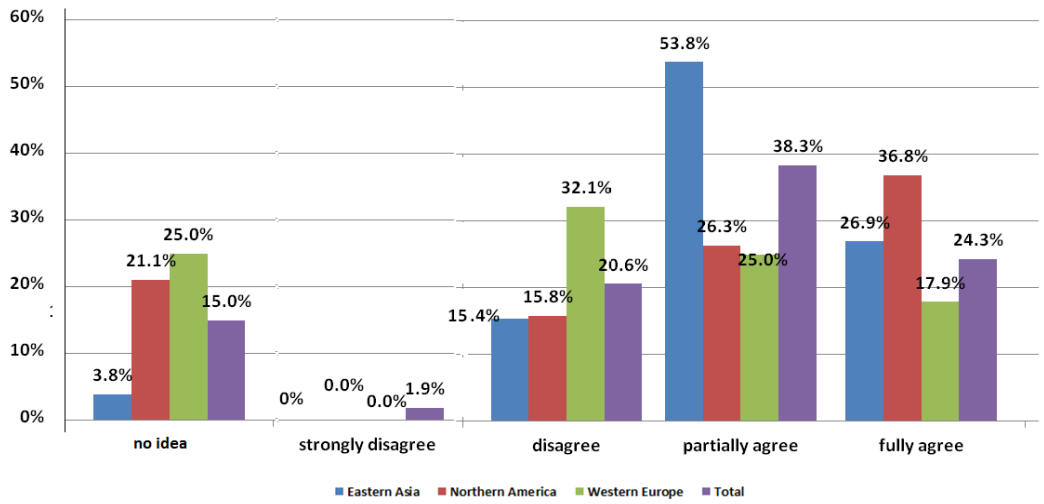


We have similar trends for all regions however different amplitudes. In East Asia nanoparticles based OPV research is the most alerting field (0.23). It is followed by small molecule based OPV

in Northern America (0.21) and East Asia (0.18). In Western Europe concerns concentrate around Nanoparticles based OPV however it is relatively low in comparison group (0.16). Other than Polymer based OPV in Western Europe, other fields are thought to be losing its research position however relatively lowers degrees.

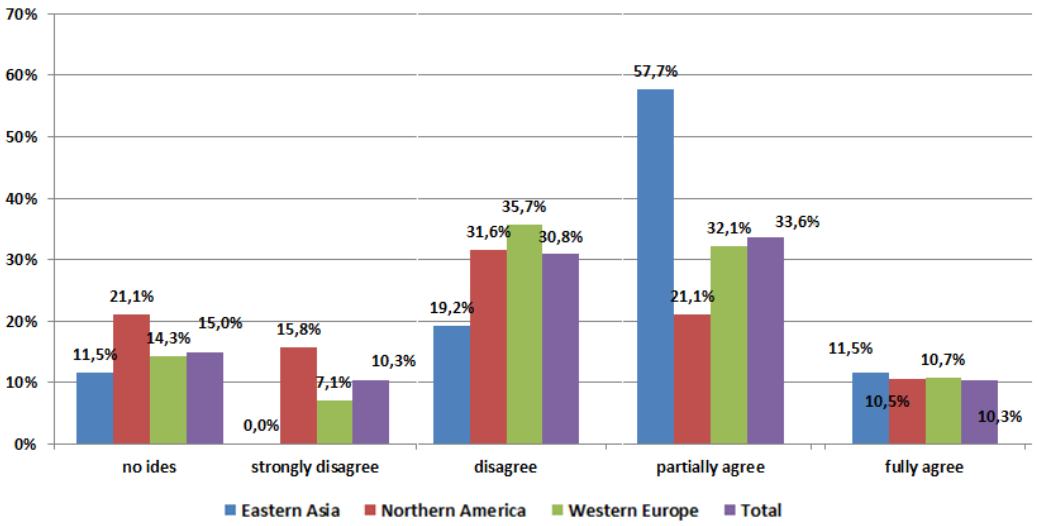
Policy support is said to be spread out over too many technologies according to the majority of the respondents. In emerging fields of innovation the portfolio is to be broad. Especially respondents in Northern America and East Asia feel that policy support is spread out over too many technologies.

Figure 8– Policy Support Spreading over too many technologies (%)



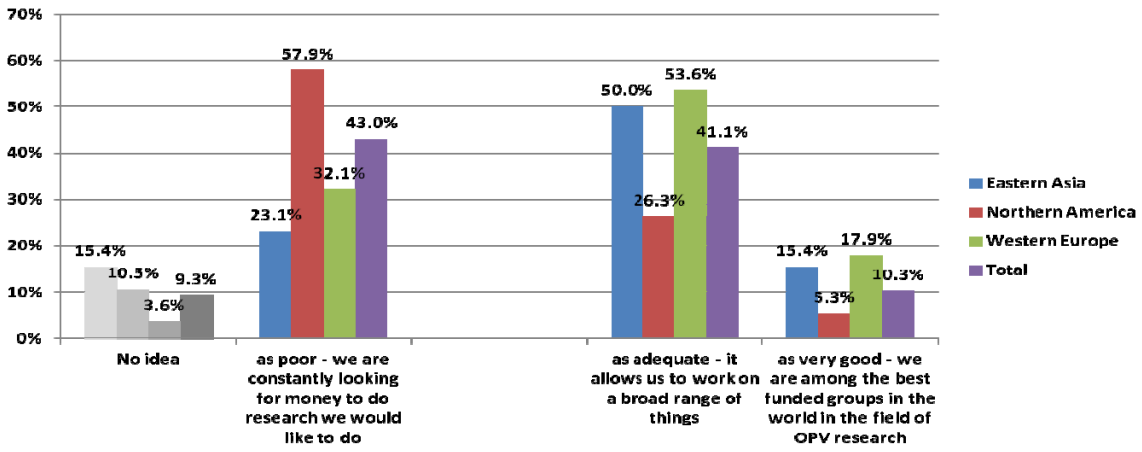
On the other hand, the answers indicate mixed views about whether the portfolio of OPV research is too broad (33.6% partially agree, 10.3% fully agree, 30.8% disagree)

Figure 9 – Portfolio Broadness of OPV Research (%)



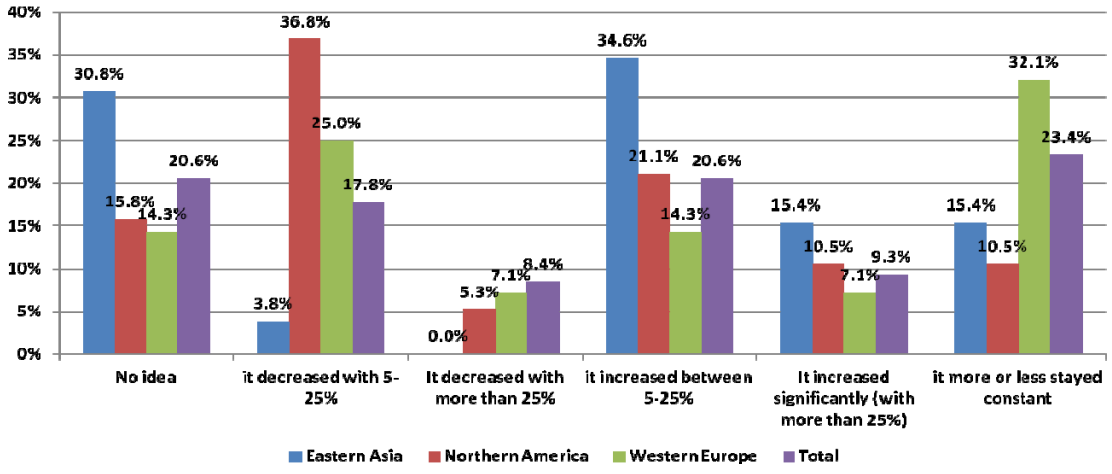
This finding leads us to analyse the level of public funding in OPV research through time. Level of public funding is considered as adequate or as very good by East Asia and Western Europe. 57.9% of researchers in North America consider the level of public funding as poor.

Figure 10– Level of Public Funding (%)



In East Asia funding levels increased between 5-25% (34.6%) and increased significantly (15.4%); in Northern America they decreased between 5-25% (36.8%) and increased between 5-25% for 21.1%; in Western Europe funding more or less stayed constant for 32.1% and decreased between 5-25% according to 25% of the respondents.

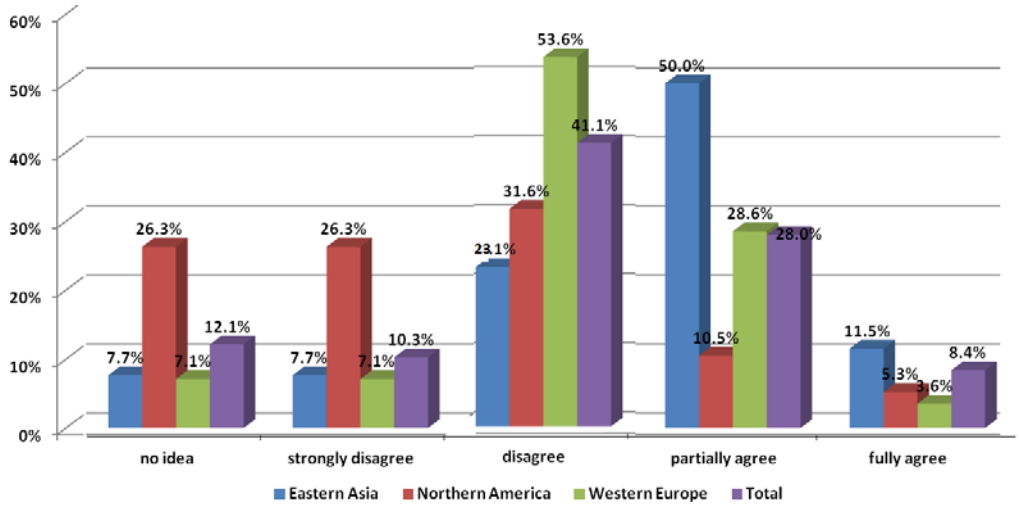
Figure 11– Funding Levels in the last 5 years (%)



We also collected opinions about whether they felt that the OPV research it too much driven by short-term industrial needs, is too much science/research-driven, or too much influenced by government/political missions. Most respondents do not think that the OPV research agenda is too much determined by short term industrial needs. 50% of the respondents in East Asia

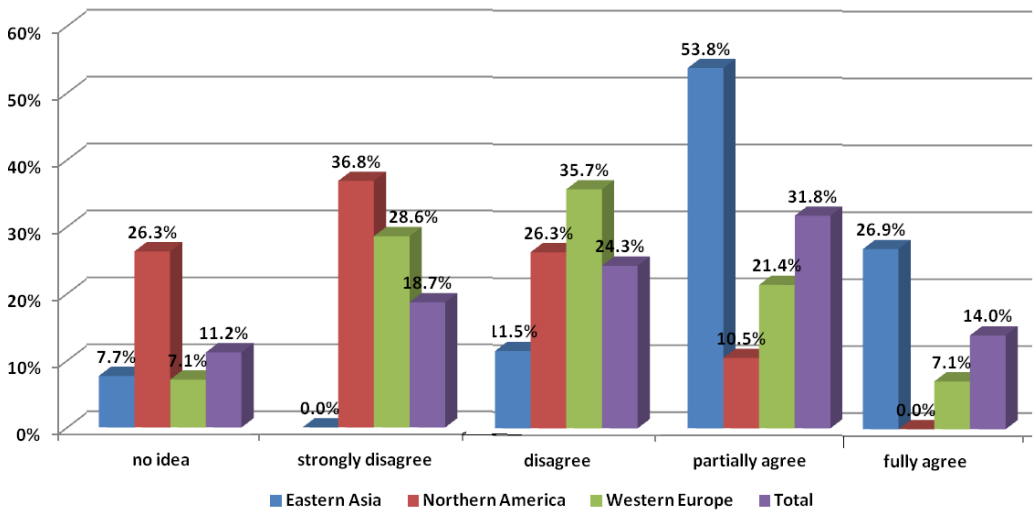
however feel that the OPV research agenda is too much determined by short term industrial needs, which is a striking difference with Europe and the US.

Figure 12 – OPV Research Agenda too much determined by Short term industrial needs



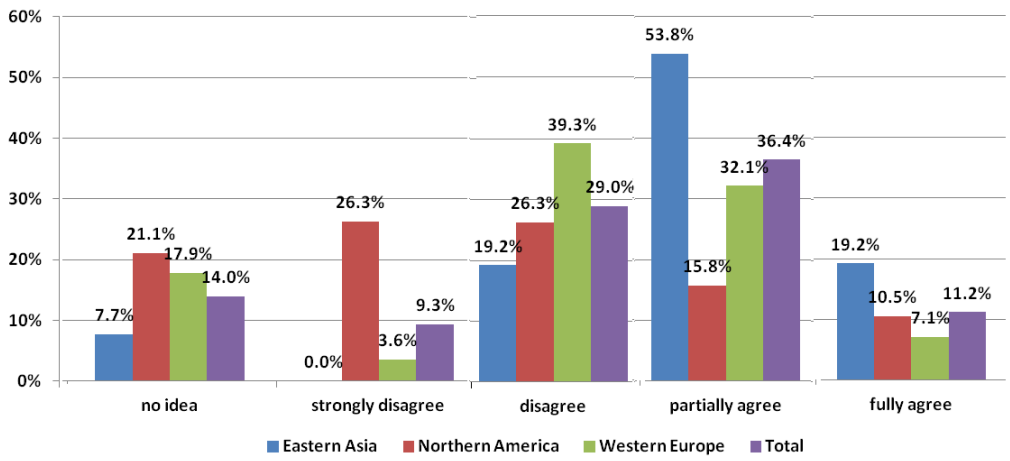
Most respondents are of the view that OPV research agendas not too much determined by science. Respondents in East Asia partially agree that the research agenda and portfolio is too much determined by science. However, there are two ways in which OPV research may be too much determined by science: through academic researchers doing what they feel like doing and through academic institutions. Letting academic institutions determine the research has the benefit of going for academic excellence. A complicating factor is that the influence of politics may be through academic institutions. Therefore we analyse political/government missions in the scene of OPV.

Figure 13- OPV Research Agenda too much determined by Science



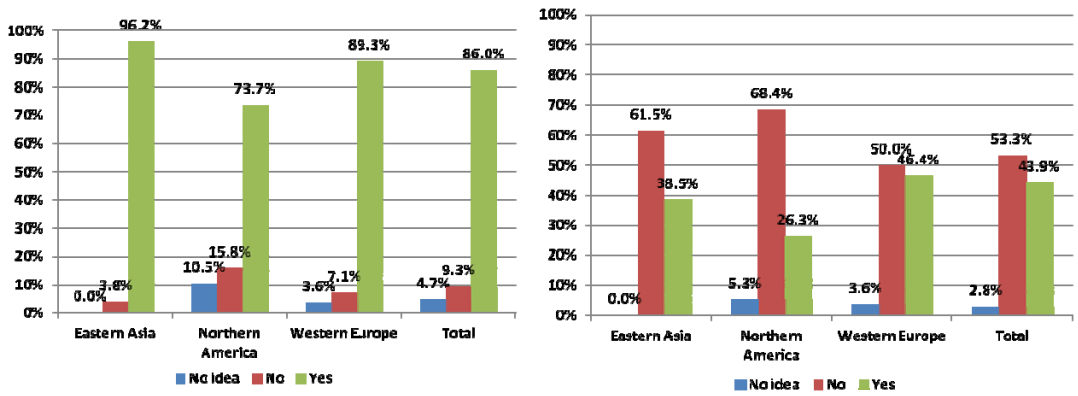
There are different views on whether OPV research agendas governments have too strong an influence on the OPV research agenda. Respondents in East Asia feel that portfolio is too much determined by science, for instance by the Chinese Academy of Sciences (CAS) who is revealed as the most active organization in OPV research and funding in China according to Web of Science query for Organic Photovoltaics.

Figure 14- OPV Research Agenda too much determined by political/government missions



In East Asia, we see a higher level of triple loadings, which means that according to the respondents, industrial needs, science, and political governmental missions are too much determining the OPV Research agenda. In Western Europe, researchers feel that the OPV research agenda is not too much determined by industry and government. A small majority feel that it too much determined by science. In Northern America, actors feel that none of the three types of actors has an unduly great influence on the OPV research agenda. The OPV research agenda appears to be more balanced in Northern America and Western Europe

Figure 15 – Partly supported through a national programme (left); benefitting from a regional (sub-national) programme (right)

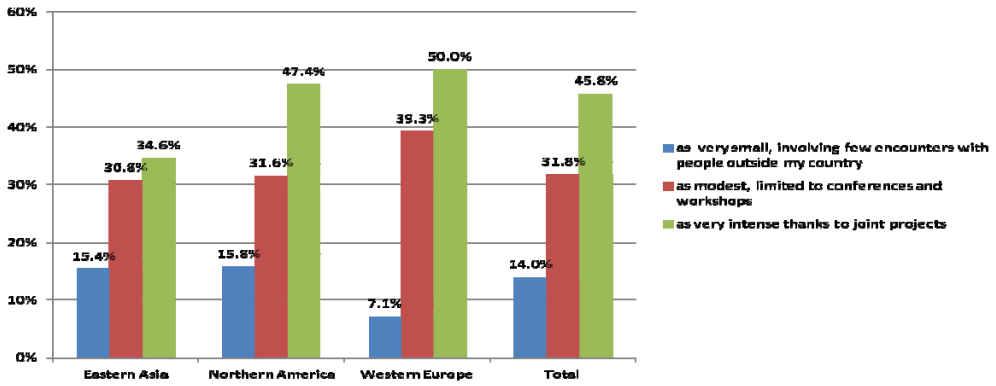


For OPV, there are both national and regional support programmes. National programmes are more prevalent than regional ones. Researchers in Western Europe benefit more from regional programmes (46.4%) than those in North America and East Asia. Regional programmes are more prevalent in Western Europe, carry positive potentials for top-down and bottom up policy mixes.

4.3. International Cooperation

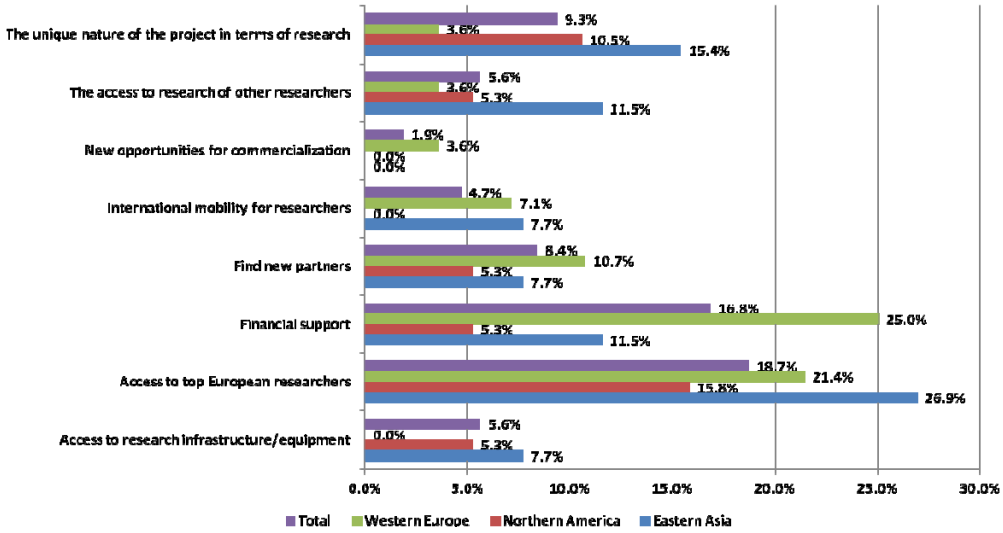
Approximately half of respondents from Western Europe and Northern America have intense cooperation / joint projects. East Asia somewhat lacks intense cooperation/joint projects, which we interpret as a negative feature of the East Asian research and innovation system for OPV.

Figure 16 – Level of International Cooperation



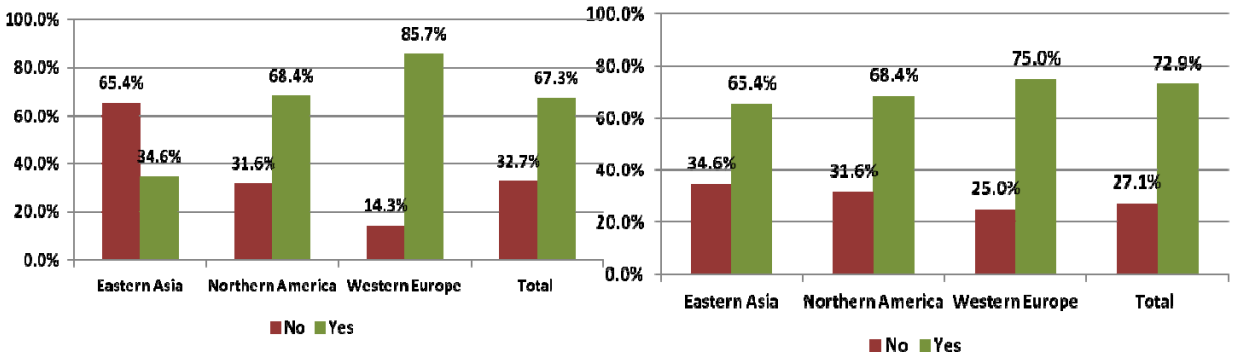
The most valuable aspect of EU projects is Access to top European researchers by East Asia (26.9%) and Northern America (15.8%). For European OPV researchers, financial support is the most important reason, followed by access to top European researchers.

Figure 17– Most valuable aspects of EU projects



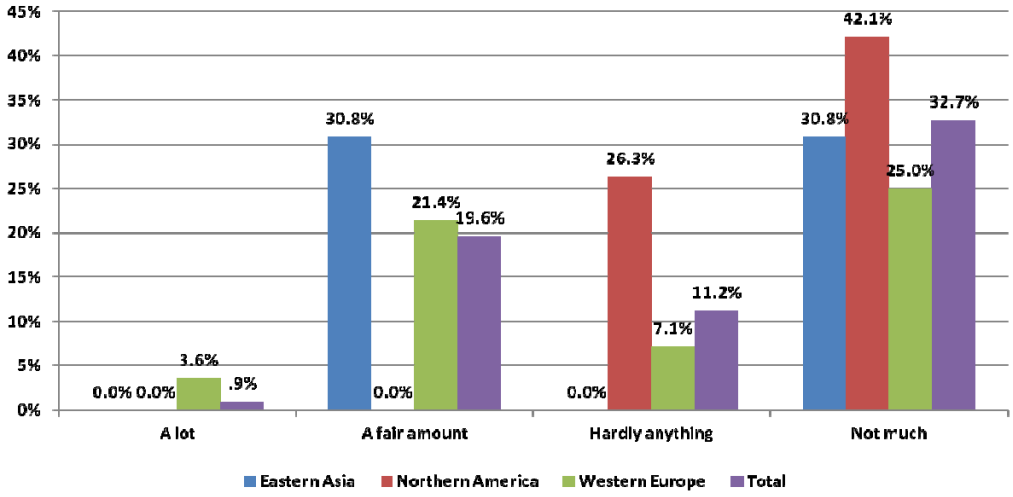
Cooperation outside Europe follows similar trend for all regions. However, Cooperation with Europe is low for researchers in East Asia (65.4%)

Figure 18 - Cooperation inside Europe (left); Cooperation outside Europe (right)



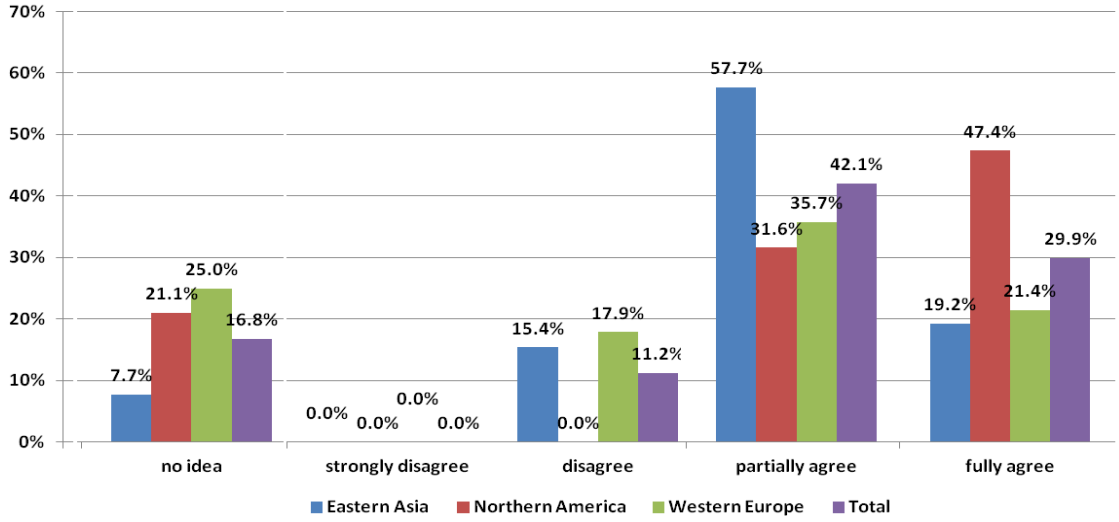
Policy coordination between the regional and national level tends to be weak in all three world regions. In East Asia (30.8%) there is a fair amount of policy coordination. East Asia and Northern America appear to have more top-down arrangements in policy than Western Europe.

Figure 19– Policy Coordination between regional and national level



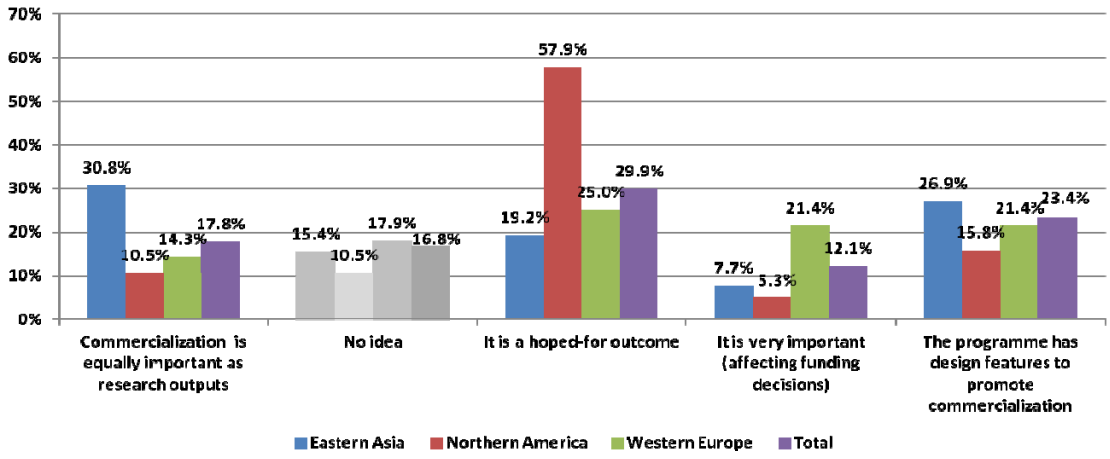
To examine the issue of policy coordination further, we asked respondents to express their agreement with the statement that "Policy support is too fragmented over programmes, funders and levels of government". The majority of the respondents consider policy to be fragmented. Policy fragmentation appears to be higher in Northern America (with 47.8% fully agreeing) and East Asia (with 57.7% partially agreeing) than in Europe.

Figure 20– Answers to statement that "policy support is too fragmented"



Given that the aim of OPV research is to produce and commercialize innovations, we analysed commercialization aspects of support programmes.

Figure 21– How important is commercialization of OPV in Support Programmes?



Commercialization is an important and hoped-for outcome for the majority of the respondents across the world. ~25% of the programmes have design features to promote commercialization. In Northern America, it is a highly "hoped-for outcome" (mentioned by 57.9% of the OPV researchers), which suggests that the North American research is more oriented towards commercialization. Curiously, commercialization is not very important for funding decisions in the US. In Northern America, only 15.8% of the OPV programmes have design features to promote commercialization (compared to 26.9% in East Asia and 21.5% in Europe).

4.4. Commercialization aspects

Barriers to commercialization with respect to the field of research reveal presence of technical and economic barriers. The results indicate that all four areas of OPV research (polymer-based, small-molecule-based, nanoparticles-based and hybrid organic/inorganic) suffer from technical and economic barriers. Technical and economic barriers are interrelated and further research is needed to investigate the precise nature of such barriers, which is why we don't comment on the differences across world regions.

Table 3– Barriers to Commercialization

Barriers to Commercialization	Polymer-based OPV		Small molecule based OPV		Nanoparticles based OPV		Hybrid organic/inorganic OPV	
	Technical	Economic	Technical	Economic	Technical	Economic	Technical	Economic
East Asia	84,0%	40,0%	82,4%	47,1%	100,0%	40,0%	90,9%	45,5%
Northern America	88,9%	50,0%	100,0%	45,5%	100,0%	16,7%	100,0%	60,0%
Western Europe	85,0%	25,0%	77,8%	27,8%	60,0%	40,0%	83,3%	16,7%
Total	85,7%	38,1%	84,8%	39,1%	87,5%	31,2%	89,3%	35,7%

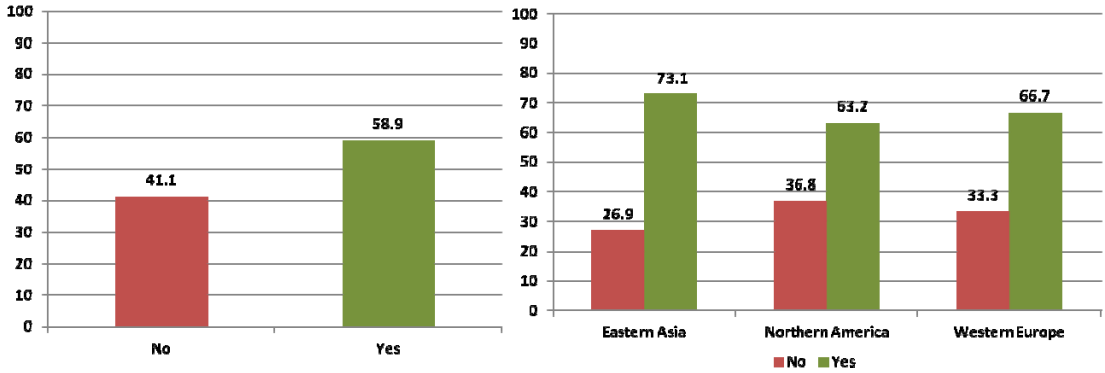
Commercialization expectations of own research are typically medium term (the period 2016-2025). Short-term expectations are shared by East Asia and Western Europe, (~22-23%), while medium term expectations are similar in East Asia and Northern America (~31-34%)

Table 4– Does your own Research have commercial value?

Does Your Own Research Have Commercial Value?	My research does not have direct commercial value	Already has commercial value	I expect commercial value in next 4 years	I expect commercialization between 2016 - 2025	I do not expect commercialization before 2025	Don't know
East Asia	19,2%	7,7%	23,1%	34,6%	3,8%	11,5%
Northern America	26,3%	15,8%	10,5%	31,6%	0.0%	15,8%
Western Europe	40,7%	3,7%	22,2%	18,5%	3,7%	11,1%

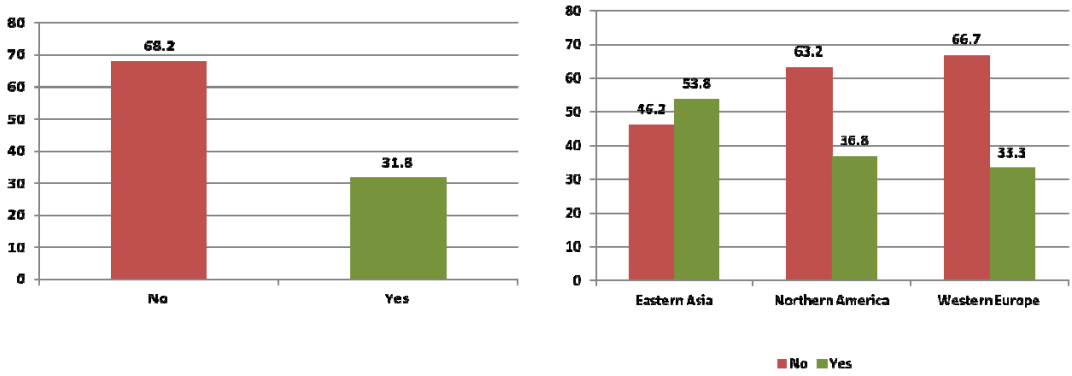
The majority of the research teams (58.9%) obtained a patent. Research teams in East Asia (73.1%) are slightly more active than other regions in patenting. Research teams in Northern America (63.2%) are *the least active* in patenting in the comparison group.

Figure 22- Obtained Patent (%) (Left); Regional Breakdown (%) (Right)



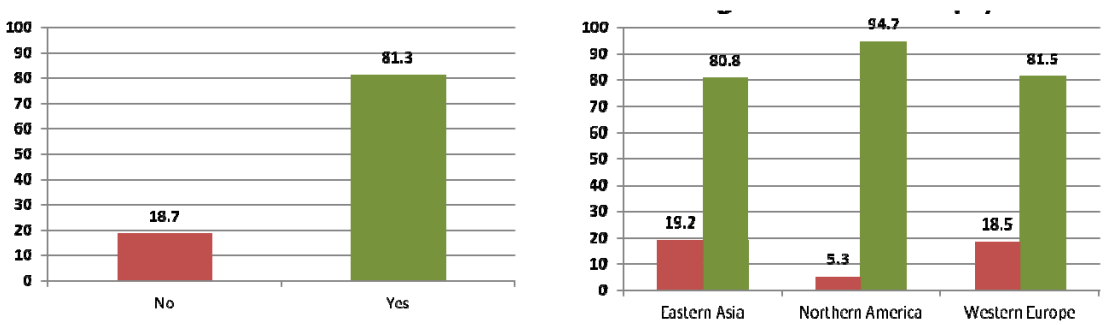
A minority of the research teams (31.8%) licensed their research findings. Research teams in East Asia (53.8%) are more active than other regions in licensing. Research teams in Western Europe (66.7%) is the *least active* in licensing in the comparison group

Figure 23- Licensing Research Findings (%) (Left); Regional Breakdown (%) (Right)



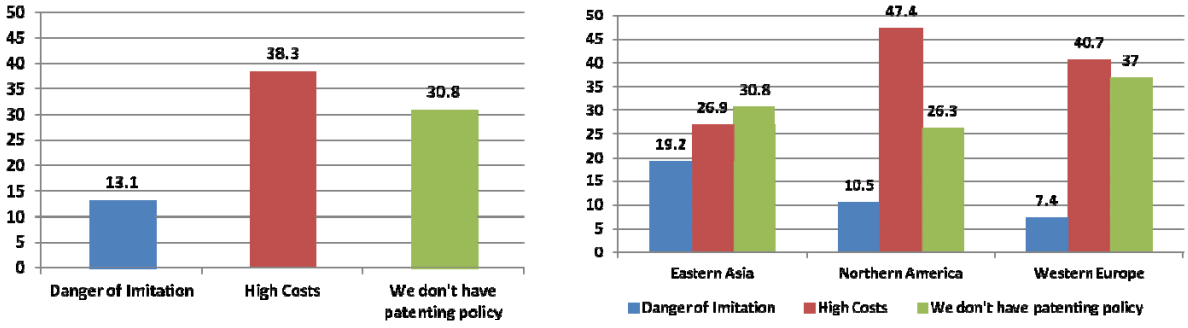
The majority of research teams (81.3%) have discoveries that are not patented. Apparently, the majority of the discoveries are not patented. 94.7% of the research teams in Northern America have discoveries that are not patented.

Figure 24- Discoveries not patented (%) (Left); Regional Breakdown (%) (Right)



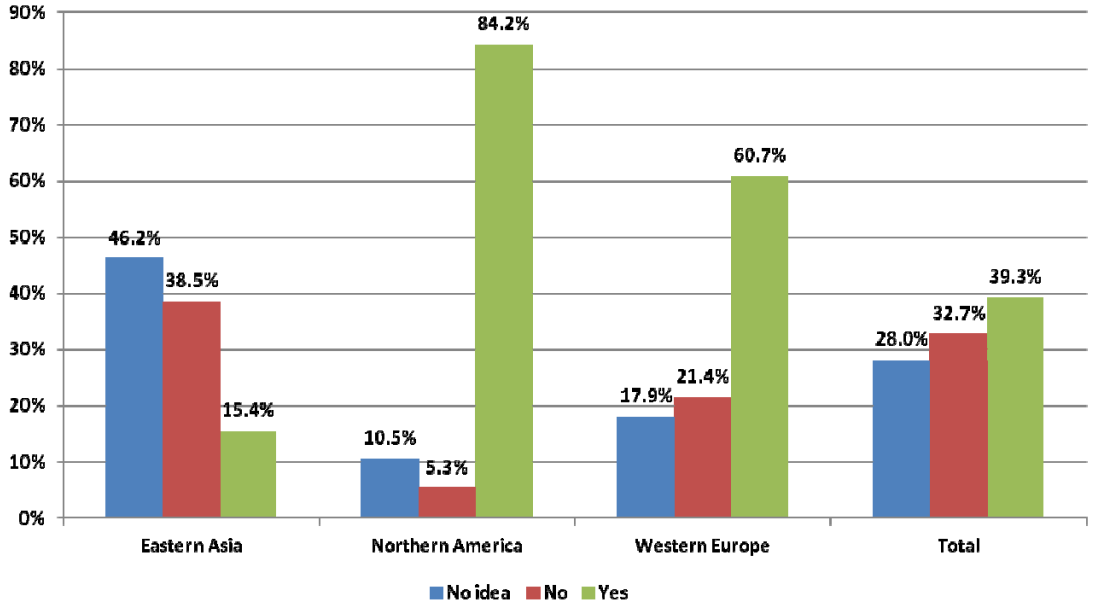
High cost of patenting is the most important reason for research teams to be able to not patent their discoveries (38.3%). High costs of patenting are quoted more frequently by research teams in Northern America (47.4%) and Western Europe (40.7%) than by researchers in East Asia (7.4%).

Figure 25- Reasons for not patenting (%) (Left); Regional Breakdown (%) (Right)



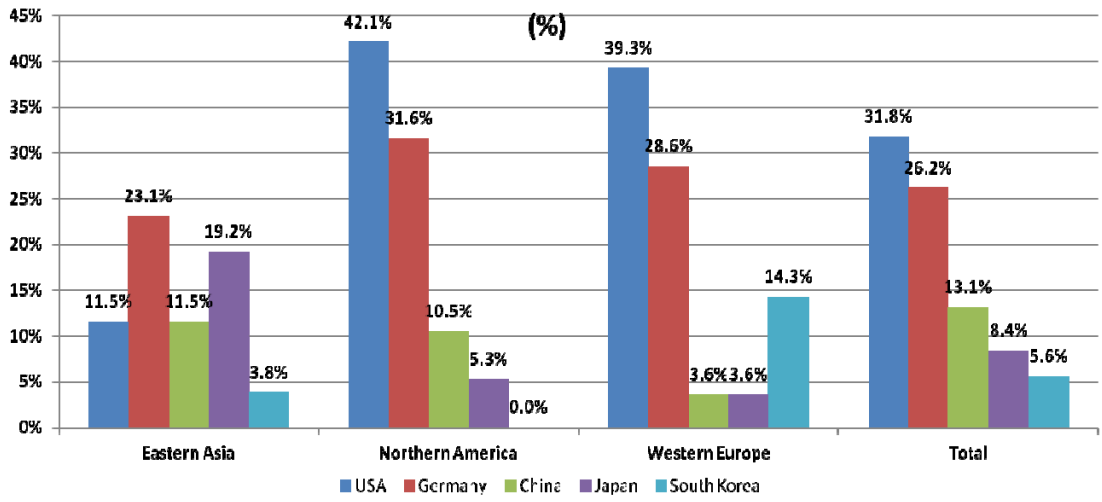
New companies (Spin-offs) to commercialize a research finding are mostly seen in Northern America (84.2%) and Western Europe (60.7%).

Figure 26– OPV Research Spin-offs (%)



USA is seen to be the most successful in commercializing OPV inventions (31.8%) Germany (26.2%) and South Korea (5.6%) are also mentioned as countries that stand a good chance at commercialization.

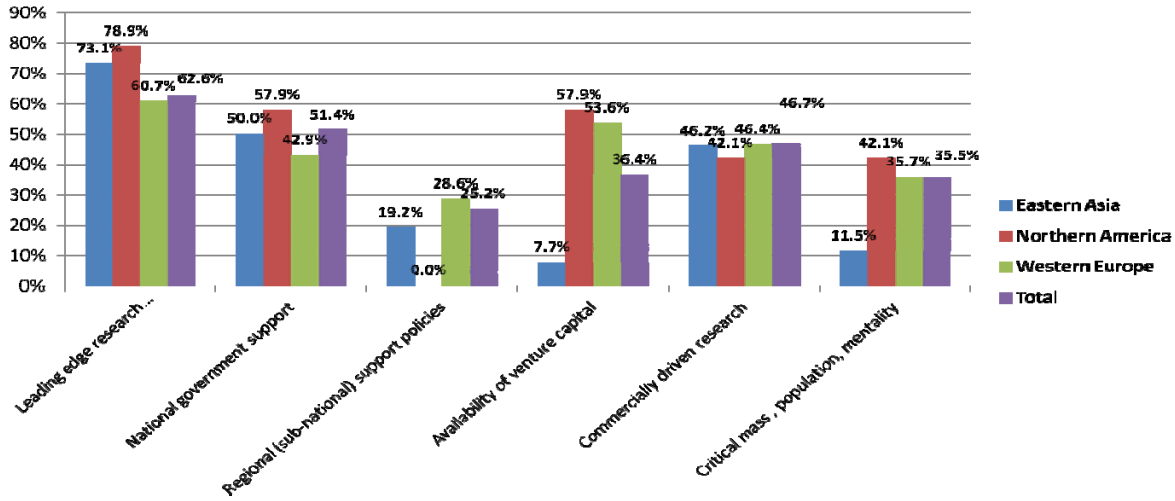
Figure 27– Likely to be most successful country in commercialization of OPV inventions



Leading Edge Research (LER) (62.6%), National Government Support (NGS) (51.4%), Commercially Driven Research (CDR) (46.7%) are seen as the top 3 factors of success for commercialization. Availability of Venture Capital (AVC) is mentioned by 36.4% of the respondents as a factor responsible for success in commercialization. In East Asia Availability of Venture Capital (AVC) as a factor for success in commercialization is mentioned by only 7.7%, compared to 57.9% in the Northern America and 53.6% in Western Europe. The difference between the scores for Availability of Venture Capital in Northern American and Western Europe is relatively small.

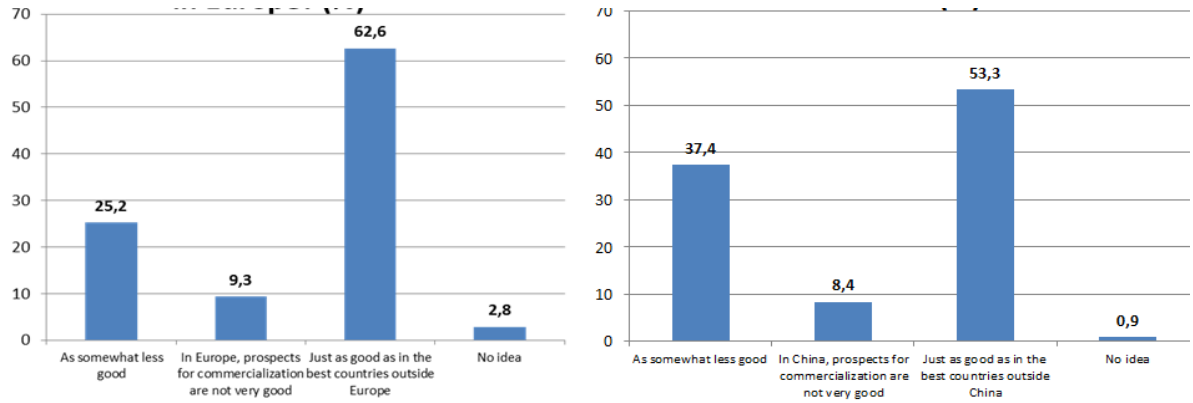
- Northern America: LER (78.9%), NGS (57.9%), AVC (57.9%)
- East Asia: LER (73.1%), NGS (50%), CDR (46.2%)
- Western Europe: LER (60.7%), AVC (53.6%), CDR (46.4%)

Figure 28 – Success factors for Commercialization



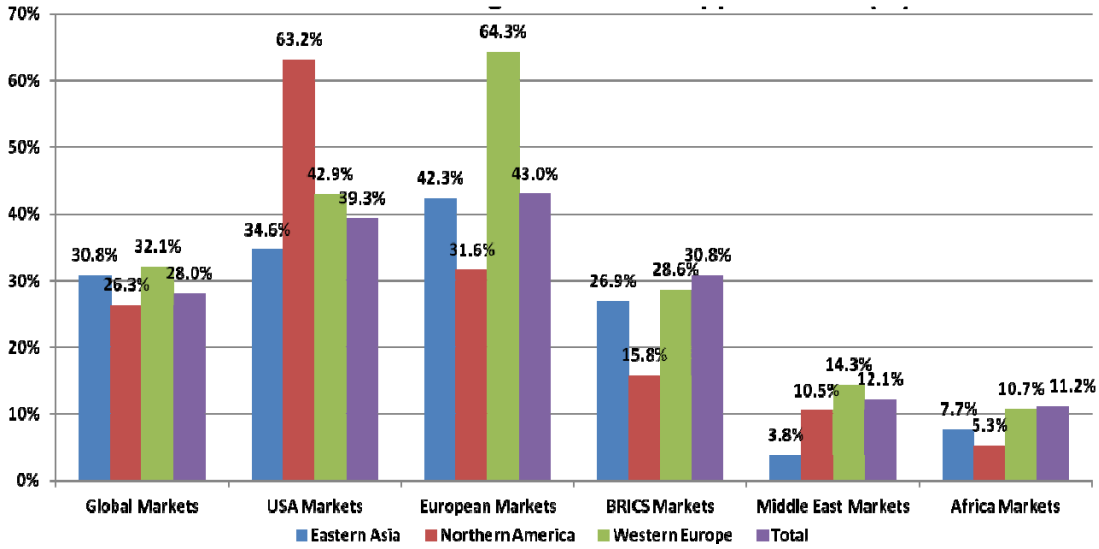
Commercialization prospects in Europe are perceived just as good as the best countries outside Europe (by ~63% of the respondents). Commercialization prospects in China are viewed as good too (but below those of Europe).

Figure 29- Possibilities for commercialization Europe (Left); China (Right)



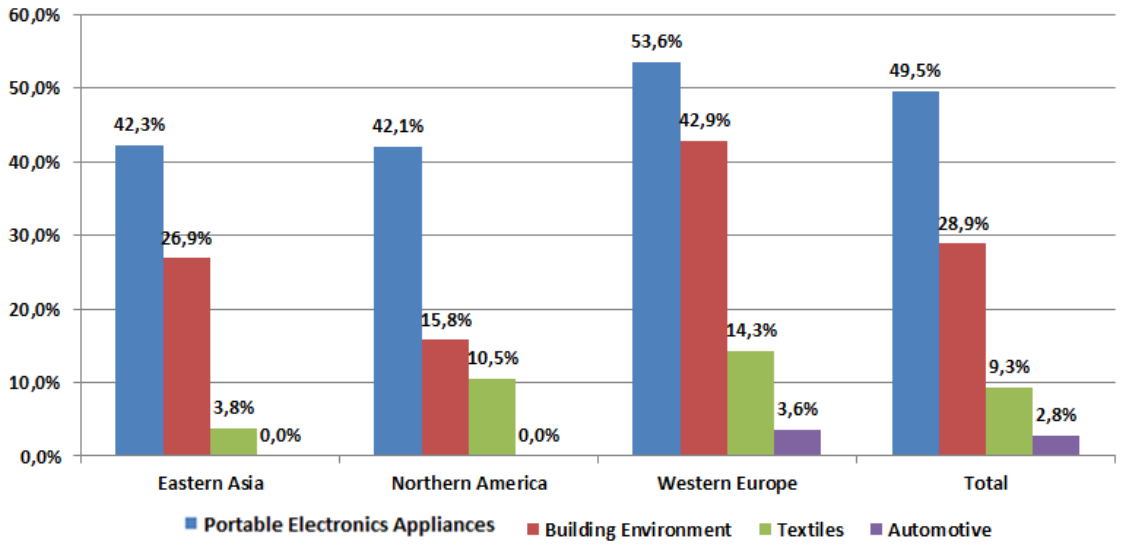
The most targeted markets are of Europe (43.0%) and of USA (39.3%). Northern America and Western Europe initially target their own markets and target more or less equally (26-32%) the global markets, Researchers in East Asia target first European (42.3%) and then markets in the USA (34.6%).

Figure 30- Which markets are targeted for OPV Applications?



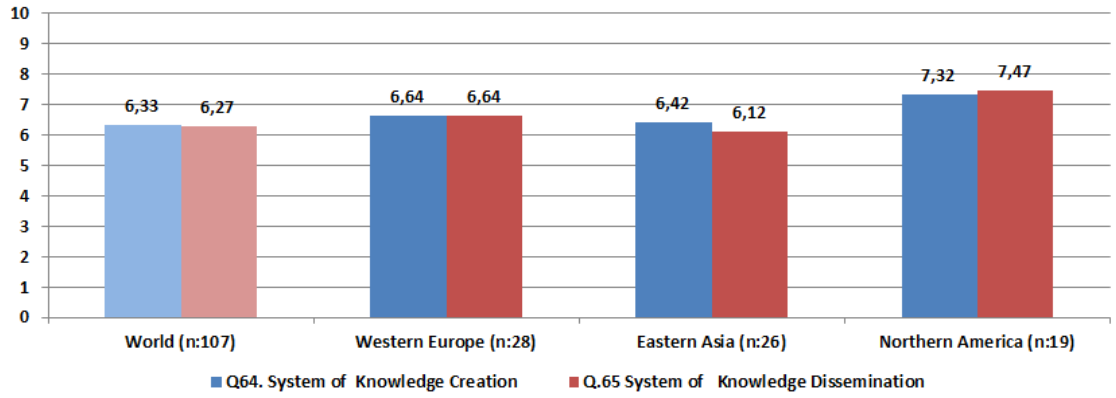
Portable electronic appliances (app. one third referring to mobile communication appliances) come out as the most important area for first market applications. In Western Europe, the Building Environment is considered an important area for first application as well.

Figure 31– Expectation on the First Market Applications (%)



We also asked respondents to score the system of knowledge creation and knowledge dissemination for OPV in their country, on a scale of 0-10 (10 being the maximum score). The scores for North America are the highest: 7.32 for the system of knowledge creation and 7.47 for the system of knowledge diffusion. The scores for East Asia are the lowest.

Figure 32 – System Scores of Knowledge Creation and Knowledge Dissemination



5. Evaluating the cognitive-institutional and political economy element

In this paper we examined the organization of research, innovation and governance for OPV in different world regions. Analyses are based on the answers of 73 OPV researchers from the regions of Northern America, Western Europe and East Asia and news articles on OPV in Lexis Nexis Academic. We observed many similarities but also some striking differences. One striking difference is that 73% of the respondents in East Asia indicated that the OPV research agenda is *too much determined by government/political missions*, compared to 39.2% in Western Europe and 26.3% in Northern America. In the PRC of East Asia, under "5-Year Plan" issued by the

federal government, the Ministry of Science and Technology (MOST) has three programmes (National High-tech R&D Programme 863, National Basic Research Programme 973, Key Technologies R&D Programme) to support PV R&D in research institutions and firms. In the US, there is less programming. Funding of OPV research occurs typically through the academic merit system. A good part of the research in the US on renewable energy occurs in the National Renewable Energy Laboratory (NREL), being the *"primary national laboratory for renewable energy and energy efficiency research and development"* of the Department of Energy, which is granted with the *"mission to develop renewable energy and energy efficiency technologies and practices, advances related science and engineering, and transfers knowledge and innovations to address the nation's energy and environmental goals''*[4]. NREL, Sandia National Laboratories, university and private-industry experts being participants, the U.S. Department of Energy, published a draft report on Organic Photovoltaics roadmap in 2007. In Europe, research and innovation policy is a matter of the nation states. At the EU level, joint research centres (JRC) have been created to offer strategic intelligence to policy makers about research and innovation issues. These centres work in close cooperation with Directorates-General of the European Commission in addressing key societal challenges.. The Institute of Energy and Transport is the JRC in the area of energy and transport is tasked with the mission *"to provide support to European Union policies and technology innovation to ensure sustainable, safe, secure and efficient energy production, distribution and use and to foster sustainable and efficient transport in Europe."*[5] *Western* Europe has a more tiered structure of OPV funding than the U.S. of Northern America and the PRC of East Asia, with a more important role for regions, while East Asia and Northern America appear to have more top-down arrangements in policy than Western Europe (see Figure 12 to Figure 15 in Section 4).

When we further analyse the result of our survey, we see more fundamental and different alignments in the organization of research and innovation in East Asia. In East Asia, policy support is considered to be spread out over too many technologies (80.7%) and the portfolio of support is considered to be too broad (63.7%). It is also believed that the OPV research agenda is too much determined by science (80.7%) and is excessively conditioned by short-term industrial needs at 61.5% level. In Western Europe, respondents indicate that the OPV research agenda are not too much determined by science (64.43%) that the broadness of OPV research portfolio is rather balanced (42.8%), and it is not excessively conditioned by short-term industrial needs. 42.9% consider the research to be spread out over too many technologies, with 32.1% disagreeing with such a statement (25% do not have an opinion on this issue). In Western Europe, 42.9% the percentage of OPV researchers find that the research agenda is too much determined by government/political missions, which is still a high percentage but one that is considerably below the percentage of OPV researchers in East Asia who think so (83%). In Western Europe, 3.7% of the respondents in Western Europe claim their inventions to have commercial value, which is

[4] http://www1.eere.energy.gov/solar/sunshot/pv_organic.html
[5] http://iet.jrc.ec.europa.eu/our-mission

lower than the US, where 15.5% of the respondents in Northern America claim that their research has commercial value already at this moment (end of 2013). 45.8% of the OPV researches in Northern America think that OPV is too much determined by science, compared to 28.5% in Europe. Another difference with Europe is that 63.1% of the respondents in Northern America consider that policy support is being spread out over too many technologies (in Europe 42. 9% of the respondents think so).

Levels of public funding in East Asia are increasing. For the last 5 years, 34.6% of the respondents indicate that the level of public funding is increased between 5-25%. 15.4% of the respondents reported that the public funding levels even increased significantly. Such significant increases are recorded by only 10.5% of the respondents in Northern America and only 7.1% in Western Europe. We have no information however on absolute levels of OPV funding.

OPV spin-off companies are only reported by 15.4% of the respondents in East Asia, against 84.2% in Northern America and 60.7% in Western Europe. East Asia could benefit a great deal from cooperation with Western Europe. There are two reasons for this: The first one is that the vast majority of the respondents (80%) consider European researchers are at the leading edge in OPV Research. The second one is that East Asia already reports cooperation outside Europe at 63% level and a lack of cooperation in Europe at 65.4% level. For them, access to top European researchers is the most important reason for participating in EU-funded projects.

In terms of targeted markets, 42.3% of the research teams in East Asia targets initially European markets and 34.6% of them the USA market, while Northern America and Western Europe initially target their own markets 63.2% and 64.3%, respectively. What are these OPV products? In our survey, respondents indicate that the first market application of OPV will most likely be in the portable electronic appliances (phone chargers/batteries, portable communication electronics etc.). One possible strategy for market success is the combination of OPV with other technologies. For instance, University of California, Los Angeles (UCLA) from USA and LG/Samsung opts for a dual technology approach*: "Polarizing organic photovoltaics (ZOPV) is a concept for harvesting energy from Liquid crystal display screens, developed by engineers from UCLA / USA. This concept enables devices to utilize external light and the LCD screen's backlight using photovoltaic polarizers. Photovoltaic polarizers convert this light into electricity which can be used to power the device. This concept also provides multifunctional capability to devices with LCD screens as they act as photovoltaic devices and also as polarizers 80% to 90% of the total energy utilized by any device with an LCD screen is used up by the backlight illumination. As polarizing organic photovoltaics can recycle up to 75% of wasted light energy, the efficiency of the device is increase."* [6] LG and Samsung already announced flexible products

[6] Kumar, Ankit; Zhu, Rui; Yang, Yang (9 August 2011). *Polarizing Organic Photovoltaics* (1). John Wiley & Sons, Inc. p. 1. doi:10.1002/adma.201101514.; Chin, Matthew; Wong Kromhout, Wileen. *"Phone losing charge? Technology created by UCLA engineers allows LCDs to recycle energy"*. Los Angeles: University of California, Los Angeles. Chin, Matthew. "*Phone losing charge? Technology created by UCLA engineers allows LCDs to recycle energy"*. engineer.ucla.edu.

that benefit from organic light emitting diodes (OLED) according to the report of NanoMarkets in 2012 and the report adds that *"…the big jump between 2015 and 2020 is attributable largely to the takeoff of the OLED lighting sector, as well as to growth in the underlying OPV and DSC PV markets, both of which will add considerably to the addressable market for flexible glass encapsulation."* [7]

In Western Europe, the building environment is reported by 42.9% as an area of first market application, a figure which is considerably above the percentages for East Asia and Northern America of 26.9% and 15.8% respectively. The high score for Western Europe may be due to its commitment to energy saving and renewable energy, which appears stronger than that in Northern America and East Asia.[8] Market expectations in the domain of transport are low, none of the respondents from Northern America and East Asia mentioned transport. Only respondents in Western Europe (3.6%) reported automotive sector as a sector for where transportation is also subject to environmentally-friendly official targets EU-wide. The EU can provide a diversifiable application/market-pull environment for researchers in Northern America and East Asia compared to their own systems, in part due to the regulatory requirements and greater attention to sustainability.

6. Concluding Remarks

OPV research, innovation and governance in Northern America, Western Europe and East Asia reflect their political economies: Northern America's market and finance orientation, liberal views, Western Europe's attention to societal benefits in its research and innovation system, and East Asia's neo-developmental state political economy, with its orientation towards international trade and export based on technological imitation and adaptation.

The results suggest that OPV as a field of technology could benefit from the following types of co-operation: scientific research policy co-ordination at policy-makers level; co-funding the OPV research under EU-level programmes; co-operation at researcher level; co-licensing and co-patenting of research findings; co-investments and co-commercialization at global but locally customized ways. Funding levels in East Asia increased in the field of OPV and remained constant while in Western Europe they fall. Opening up Chinese OPV research programmes would strengthen OPV research in China globally. The benefits of the above would be scientific learning for China, (venture capital) funding for Europe and a programmatic structure for OPV research in Northern America, helping OPV research groups to interact with other groups and actors, each of which have different competences and resources in their social networks. Actually, some of what we propose is already happening. Examples are the Danish-Chinese

[7] NanoMarkets (2012), *Flexible Glass Markets, 2013 and Beyond*, http://nanomarkets.net/Downloads/ES/FlexglassES.pdf

[8] An example of this commitment is Directive 2010/31/EU (EPBD recast) of which Article 9 requires that "Member States shall ensure that by 31 December 2020 all new buildings are nearly zero-energy buildings. http://www.epbd-ca.eu/themes/nearly-zero-energy

Center for Organic-based photovoltaic cells with morphology control[9], and Solar Press UK Ltd. founded in 2009, a joint venture between the Carbon Trust and C-Change. The Carbon Trust operates globally through offices in London, Beijing and New York, and particularly active in the UK, South Korea, China, and the USA[10]. This illustrates the relevance of our analysis, which could be applied to other fields of emerging technologies.

Limitations of the analysis are the reliance on researchers and research managers as the source of information and the neglect of varieties of capitalism and political economy aspects within the world regions. A bigger sample, a rerun of the survey in a few years of time, and the use of interviews with funders and researchers would help us to probe the issues of investigation deeper than we have been able to do. At the same time we feel that the results have value, and that our approach could be developed into a practical tool for advice on international research and innovation cooperation and national reforms in research and innovation governance (in cooperation with innovation policy makers), and a scientific tool for political economy analysis (by probing deeper into the issue of the interplay between interests and ideas).

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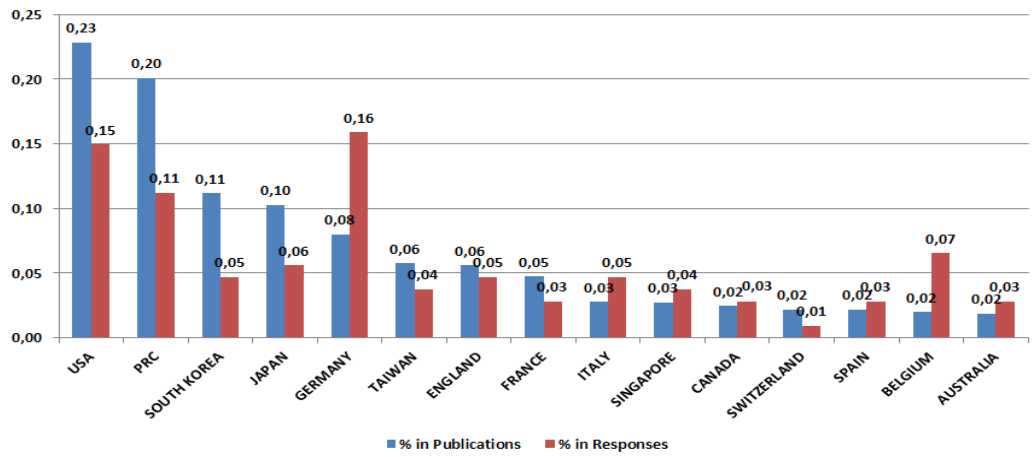
APPENDIX - Basic Information: Profiles of Respondents: In 6 weeks, out of 142 responses received, 107 responses were valid (average overall response rate 10%). Number of Publications is derived from Web of Science query "Organic Photovoltaics" from 1988 to 2013 January 1. We did not get responses from **Austria and Netherlands** as important countries even after sending three reminders. However, we received relatively higher percentages of responses than of percentages of publications from Germany and Belgium.

Figure Appendix 1- % in Publications in OPV vs. % in Responses in OPV Survey



Roles in Research: Presence of Multiple Roles

Occupational distribution is seemingly balanced for 107 responses. 29.9% of the respondents (n: 32) are researchers in the field of OPV, 36.4% is project leader (n: 39). 33.6% is both researcher and project leader (n: 36). 70.1% of the respondents (n: 75) are researchers or both a project leader and a researcher. 63.6% of the respondents (n: 68) are project leaders or both a project leader and a researcher. 66.4% of the respondents (n: 71) declared a single role being either project leader or researcher, while 33.6% (n: 36) reported dual role being both researcher and project leader.

Table Appendix 1 - Roles in Research: Presence of Multiple Roles

Roles in Research/Geo	East Asia	Northern America	Western Europe	Total
As a project leader	7	4	6	17
	9,6%	5,5%	8,2%	23,3%
As a researcher	8	4	16	28
	11,0%	5,5%	21,9%	38,4%
As a researcher, As a project leader	11	11	6	28
	15,1%	15,1%	8,2%	38,4%
Total	26	19	28	73
	35,6%	26,0%	38,4%	100,0%

Inter- Organizational Occupations: Single Organizational Occupations

72.9% (n: 78) of the respondents work in a university, 23.4% in a government institute, 5.6% in a research centre and 3.7% a business company. Number of places where OPV research is conducted, 93.5% reported a single organization where 6.5% reported two organizations. Among other combinations (a business company and a university (n: 1), a business company and a government institute (n: 1), 0.9% each) 4.7% work in a university and a government institute (n: 5), as the most observed combination.

Table Appendix 2 - Inter-Organizational Occupations in Research in Major World Regions

Inter- Organizational Occupations /Geo	East Asia	Northern America	Western Europe	Total
A university	15	18	19	52
	20,5%	24,7%	26,0%	71,2%
A government institute	8	0	3	11
	11,0%	0,0%	4,1%	15,1%
Research centre	0	0	5	5
	0,0%	0,0%	6,8%	6,8%
A university, A government institute	2	0	1	3
	2,7%	0,0%	1,4%	4,1%
A university, A business company	1	0	0	1
	1,4%	0,0%	0,0%	1,4%
A business company, A government institute	0	1	0	1
	0,0%	1,4%	0,0%	1,4%
Total	26	19	28	73
	35,6%	26,0%	38,4%	100,0%

Spatiality: Regional information of respondents, regions included in the major region analysis are given bold

Table Appendix 3 – Respondents' Local/Regional Breakdown

Region	n	%
Belgium - Vlaams-Brabant Region	6	5,6
Germany - Saxony Region	5	4,7
USA - California Region; USA - Texas Region; Singapore - Singapore Central Region	4	3,7
Spain - Barcelona Region ; **Japan - Kanto Region; Germany - Rhineland-Palatinate Region; Germany - NRW Region; Germany - Baden-Württemberg Region**	3	2,8
USA - Colorado Region; UK - Yorkshire Region; **Taiwan - Northwestern Taiwan Region; South Korea - Seoul Region; South Korea - Hoseo Region; Japan - Chūbu Region**; Italy - Emilia-Romagna Region ; **Germany - Niedersachsen Region; China - Tianjin Region; China - Shanghai Region; China - Beijing Region; China - Anhui Region**	2	1,9
USA - Tennessee Region; USA - Pennsylvania Region; USA - North Carolina Region ;USA - Massachusetts Region USA - Iowa Region; USA - Illinois Region UK - Wales Region; UK - South West England Region ;Turkey - Marmara Region Turkey – Middle Anatolia Region ;**Taiwan - Southwestern Taiwan Region; Taiwan - Northern Taiwan Region; Switzerland - Basel Region;** Sri Lanka - Central Province Region ; Spain - Madrid Region ; Russia - Nizhny Novgorod Region Russia - Moscow Region ;Portugal - Lisbon Region; Lithuania - Lithuania Region; **Japan - Chūgoku Region;** Italy - Piedmont Region; Italy - Lombardy Region ; Italy - Calabria Region; Israel - Negev Region; Israel - Haifa Region; **Germany - Hessen Region; France - Pays de la Loire Region; France - Midi Pyrénées Region; France - Aquitaine Region;** Finland - Pirkanmaa Region; Ethiopia - Addis Ababa Region; Denmark - Nordjylland Region; Cyprus - Limassol Region; **China - Zhejiang Region; China - Jiangxi Region; China - Jiangsu Region; China - Fujian Region; Canada - Quebec Region; Canada - Ontario Region; Canada - Alberta Region**; Brazil - Parana Region; **Belgium - Limburg Region**; Australia - Victoria Region; Australia - South Australia Region ; Australia - Queensland Region	1	0,9
Total	**107**	**100**

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