INNOVATION ECOSYSTEMS: GREATER THAN THE SUM OF THEIR PARTS?

Graca Carvalho[1*], Alisdair W Ritchie[2], Evan D Fradkin[2]
[1]Department of Computer Science, University College London, UK and
Centro Algoritmi, Universidade do Minho, Braga, Portugal
[2]Cyber Security Centre, University of Warwick, Coventry, UK.
**Graca.Carvalho@ucl.ac.uk*
***Keywords**: IoT Research, Cybersecurity, Innovation Ecosystems, PETRAS, Evaluation, Innovation Framework*

Abstract
The challenges of the future are multidisciplinary and will require ideas which are nurtured and developed into products, services and businesses within Innovation Ecosystems. This paper will examine what underpins innovation ecosystems and what makes them a success using the PETRAS research hub as a case-study to evidence these principles.

1. Introduction
Bringing IoT technology to bear on the challenges of the future and realise their full potential will be essential if the UK government is to achieve the grand challenges set out in its Industrial Strategy [1] but this is not an easy task [2] and requires collaboration across different divisions of social, technological, and regulatory domains as well as collaboration across different research disciplines [3]. These divisions, which are reinforced by stereotypes, language, and self-interest lead to perceived incompatibilities that hinder innovative thinking. In order to foster innovative thinking an ecosystem that helps loT technology address these challenges must be introduced.
The purpose of this paper is to examine “Innovation Ecosystems” [4][5] to facilitate high-impact collaboration and promote innovation.
To achieve this, this paper will apply a framework proposed by Innovate UK [3.1] to evaluate whether Aristotle's eponymous statement "the whole is greater than the sum of its parts” also applies to Innovation Ecosystems.
As a case study to validate these hypotheticals it will use as evidence the PETRAS National Cybersecurity of the lnternet of Things research hub that aimed to describe the safe deployment of research into real world environments whilst working with different echelons of society.
As an aid to structure, the reader should be aware that this paper is broken down into sections:
1) Introduction
2) What are Innovation Ecosystems?
3) Evaluation Methodology
4) PETRAS Innovation Ecosystem – Evaluation
5) Innovation and Evaluation Framework – Key Findings
6) Conclusion

2. What Are Innovation Ecosystems?
An innovation ecosystem models the economic dynamics of the complex relationships that are formed between actors or entities whose functional goal is to enable technology development and innovation. In this context, the actors include the inputs (funds, equipment, facilities etc.) and the human capital (researchers, managers, industry partners etc.) that constitute the institutional entities participating in the ecosystem. Innovation ecosystems are driven by two different economies, the research economy, led by fundamental research and the commercial economy, which is led by the marketplace [4].
Occasionally, research programmes are put in place that offer incentives to the creation of innovation ecosystems. The ComPaTrIoTS [4.1] call aimed to fund a Research Hub that would address the challenges around Privacy and Trust in the Internet of Things. The PETRAS cybersecurity research hub was established as the winning consortia of this call and sought to address the sociological and technical issues that influence the evolution of the Internet of Things.
For this paper, it has been chosen as an exemplar of cross-discipline collaboration between universities, industry and government. The research it carried out ranged from blue-skies thinking to applied research to physical demonstrations of the safe deployment of research into real world environments through collaboration with industry partners.
According to Innovate UK’s classification index [3.1], PETRAS is a Level 3 programme (High Budget – High Risk). This means that it is a large project with significant budget and/or high profile with media and public interest. It also has potentially high impact which also has a complex programme design and/or significant risk and uncertainty around programme outcomes. Level 3 is the highest complexity level in the index and these programmes require evaluation frameworks that should be rigorous and detailed to be relevant. All of the above justifies the choice of PETRAS as the innovation ecosystem that this paper will be focused on.

3. Evaluation Methodology
The Evaluation Methodology proposed by Innovate UK [3.1] follows a series of steps that start with the creation of a logic model. It then suggests that the evaluation should be embedded in the project itself so that information can be continuously gathered. Different approaches to monitoring are suggested, with a combination of Qualitative and Quantitative methods and a holistic approach to promote a global view of the programme being evaluated. Another important recommendation is that the evaluation should use, whenever possible, multiple data sources, internal and external.
According to the proposed framework, a complete evaluation exercise encompasses three types of evaluation:
Processes evaluations look at how a programme was delivered. They typically include a mixture of quantitative and qualitative methods used to understand the programme’s

financing and resourcing, perceptions of quality and effectiveness, and facts and figures on the operation of a programme. These evaluations are directly related to programme management activities.

Impact evaluations look at the difference a programme has made:

- What were the observed outcomes?
- How much of any observed change in outcomes can be attributed to the programme?
- How did changes vary across groups?
- Were there any unintended outcomes? Did the programme achieve its objectives?

Economic evaluations look at whether the benefits of a programme justify its costs. This would show whether the processes are efficient, effective and demonstrate whether the programme is justified in terms of benefits compared to costs.

4. PETRAS Innovation Ecosystem - Evaluation

This section will cover PETRAS as our evaluation exercise of an innovation ecosystem. As part of the evaluation of the wider IoTUK Programme in which PETRAS sits, DCMS commissioned SQW (www.sqw.co.uk), a commercial public policy research institute, to create of a Logic Model for PETRAS. The authors used that logic model as the basis for this evaluation exercise and to support the creation of several KPIs. These KPIs were presented to PETRAS Principal Investigators at the 3rd Operations Group Meeting in September 2016 and addressed three layers: the processes layer, the research innovation layer and the socio-economic layer.

4.1. Process Evaluation Layer

The PETRAS Strategic Objectives presented at the 3rd Ops Group meeting in September 2016 and which were widely communicated to the PETRAS community at the PETRAS Bi-Annual event in November 2016:

- Delivery of tangible, actual co-created impactful and cross-sectoral technological and socio-economic benefit.
- Position UK as world-leader in expertise and deployment of trusted IoT Technology.
- Create a cross-disciplinary language and framework across research domains, industries, and government departments.
- Create a social platform for innovation and co-creation with Users and Stakeholders.
- Create an enduring legacy from the PETRAS Hub beyond the end of the funded period.

Governance – The governance structure evolved over time but in its final version it constituted 4 main groups. A user research board which constituted the hub's industry partners; an operations group which was made up of the eleven university's Principal and Co Investigators, including the hub management team, which was responsible for day to day management of the hub; a steering board with an independent chair which was drawn from government, industry and academic parties and finally a science panel to provide expert advice to the operations and steering groups.

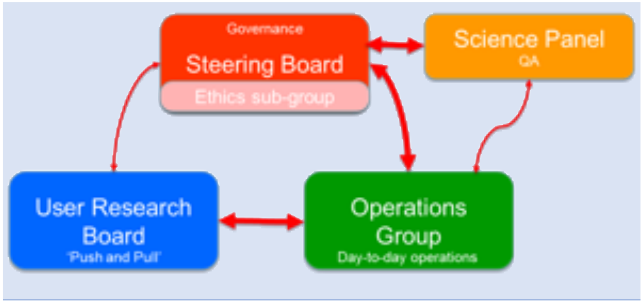

Figure 1: The PETRAS Governance structure

Socio-Technical Streams. PETRAS projects were associated with at least one, or it could be up to all five, cross-cutting socio-technical streams. These streams were Harnessing Economic Value; Adoption and Acceptability; Safety and Security; Standards, Governance and Policy; and Privacy and Trust. These five streams were led by both a technical and a social academic lead drawn from across the hub's core university partners and were each funded with 50% of a researcher for 3 years.

Figure 2 shows how the effects of an innovation ecosystem, where rather than funding completely separate streams of research, the end result facilitates interdisciplinarity.

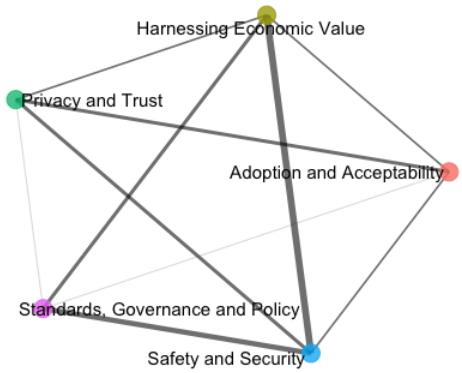

Figure 2; The PETRAS ecosystem of projects viewed by stream (the thickness of the line indicates rising collaboration between the streams as measured by projects shared).

Constellations - Application Themes: PETRAS projects were aligned with five key industry sector groupings or constellations. The purpose of this was to make sure that projects produced results that were of real-world value to those companies operating within given key sectors. This alignment became of increased importance the higher Technology Readiness Level (TRL) of the individual project.

Impact Team and Impact and Comms Board - PETRAS facilitated creation of impact and innovation through its Impact Team. This was a team of 6 full time operational staff who were responsible for driving the wider range of activities, events, income and research outcomes that the hub generated. This impact team formed the core of an Impact and Comms board which met once every six months and brought on board a wider range of senior academic staff from across the hub in order to bring integrate the full breadth of activity. The Impact and Comms board reported regularly to the PETRAS

management team with the PETRAS Impact Champions represented in both groups.

User-Research Board workshops - Every 6 months the Hub hosted a 1-day conference to which all members of the Hub and Industry partners, along with perspective industry partners were invited. This usually followed a day where all Hub members (researchers) attended a strategy day or training.

This Bi-Annual meeting consists of reports on work being undertaken by the hub, an exhibition of posters and demonstrations, key note speakers and debates amongst industry and academia colleagues. Crucially it gave an opportunity for the Hub and its researchers to canvass industry opinion, either informally in one-to-one conversations, or during formal sessions. Furthermore, it created a focal point and showcase for interaction between the hub and its partners. The Meeting would regularly attract upwards of 150 industry attendees.

PDRA Mobility Fund - PETRAS made available funds to support researchers to take collaborate with to industry or government partners.

The fund enables researchers to work with organisations deploying technology developed within the hub or adapting it for specific industrial purpose. This could be in the form of workshops or secondments. It also enables the flow of insight from within the industry back to the hub informing further research and inspiring future projects.

4.2. Research Innovation Evaluation Layer

In the PETRAS Innovation Ecosystem domain, Impact Evaluation refers to the Impact of the Research Innovation that the hub has produced. In line with [8], we will present how R&D activities for emerging technology domains like IoT can be modelled as Innovation Ecosystems. We will present the network of collaborations that emerged in PETRAS and provide an analytical framework to identify the factors that contributed to the creation of those collaborations. The paper will also provide an assessment of the major outputs of the hub focusing on the innovation outputs. Lastly, the paper will present recommendations that can be used to create new multi-disciplinary research hubs where the interaction of multiple actors is a key success factor.

Publications - Figure 3 shows the number of publications that were produced as part of the initial funding agreement (PETRAS Deliverables) versus the total number of publications that were published by the PETRAS Ecosystem. The number of publications for PETRAS deliverables was calculated by summing the publications that were attributable to a given PETRAS project. The number of PETRAS Ecosystem publications was calculated by summing the number of publications that weren't attributed to a given project.

Demonstrators - All projects are expected to be able to contribute to the demonstration of technology innovations resulting from the research undertaken in the hub. In its final year, PETRAS funded several demonstrators through a strategic research fund call to its partners.

The demonstrators took the findings from a range of projects within PETRAS and combined them in response to a problem statement from industry to produce a demonstration of the safe deployment of IoT technology in a real-world environment. In all, PETRAS created 10 demonstrator projects, of which 6 were funded into demonstrator projects with additional support coming from the Lloyd's Register Foundation and industry partners. These demonstrators exhibited their work to a public audience over the course of February 2017 with additional exhibits of their work going into an event at the House of Lords and the Tate Modern.

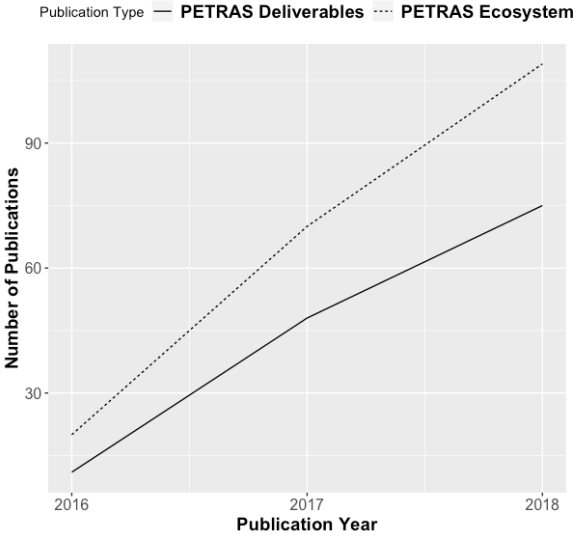

Figure 3: Publications from the PETRAS ecosystem

Research Scope –The hub funds research projects undertaken within the 11 universities. These include the initial projects outlined in the funding bid for the hub and further projects successful in funding calls from the hub. All research projects have an active industry partner and should show a demonstrable impact on that partner. Where a partner does not already exist the Impact team would help identify to one.

All engagement with industry is tracked and reported on to the hub. Academics are encouraged to share their findings as widely as possible in both academic journals but also industry focused outputs including white papers and industry conferences.

All research in PETRAS is categorised within both research themes (aligned with letters of PETRAS the acronym) and Application areas,

- Infrastructure
- Supply and Control systems
- Transport and Mobility
- Ambient Environments
- Healthcare

This enables the clustering of work and outputs from both an industry and academic perspective, facilitating interactions.

- Mapping of Projects into Streams.
- SRF 1 and SRF 2 – Gap and new areas – Blockchain example

PRF (Partnership Research Fund) - Within the projects initial bid, funds were ringfenced to enable ad-hoc small projects with industry to be undertaken. Up to £50,000 can be applied for to enable exploratory research between an industry partner and an academic.

These funds are specifically aimed to enable the formation of new collaborations. To enable this the application for funds was an on-going call with a fast turn-around. Only accepting

applications for small projects de-risks funds being channelled on unsuccessful projects but does pose some operational difficulties in managing a larger number of contracts and projects.

The fund provides a framework for industry partners to contribute actively to the hub with either in-kind or financial resources.

It is intended that successful projects from this fund will then go on to apply for a substantial project with the Hub or seek funding elsewhere in collaboration with Hub members.

Engagement Activities - PETRAS as an organisation was dynamic and positive about engaging with its user partners (government and industry), the general public as well as the academic community. Over the course of its three-year lifetime PETRAS recorded more than 650 different engagement events, a rate of more than 4 events per week. These ranged from co-hosting a two-day event in February 2019 at the Tate Modern with the Tate itself where almost 1,400 members of the general public were able to viscerally interact with the PETRAS Internet of Things world to thematic workshops which investigated specific topics such as the GCHQ/PETRAS Future of IoT workshop held at the University of Oxford in November 2018.

Figure 4, 5 and 6 show how the wide range of activities within PETRAS were categorised. The three most common types of activity were talks or presentations, formal working groups or expert panels and thematic workshops, with almost a quarter having an international reach and a quarter each addressing academic and industry audiences.

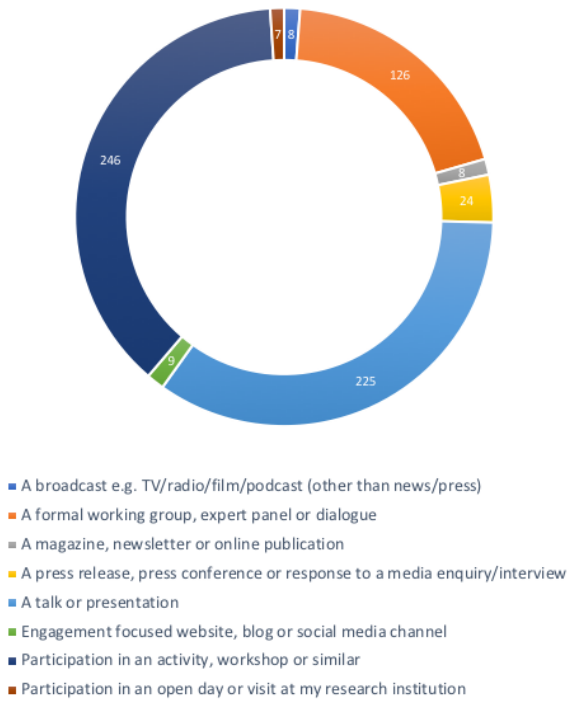

Figure 4 – Type of engagement within the PETRAS ecosystem

4.3. Socio-Economic Evaluation Layer

This paper will examine the PETRAS programme as it has evolved over time and through the evolution of its engagement with its partners and through the amount of money that has been brought in through its ventures with its partners. It will also seek to show through the evolution of this ecosystem how its reach expanded over time and the importance of building such an ecosystem in the successful development of the programme.

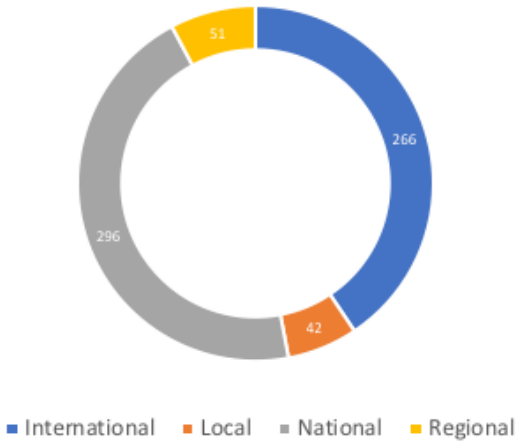

Figure 5 – Geographic reach of PETRAS Events

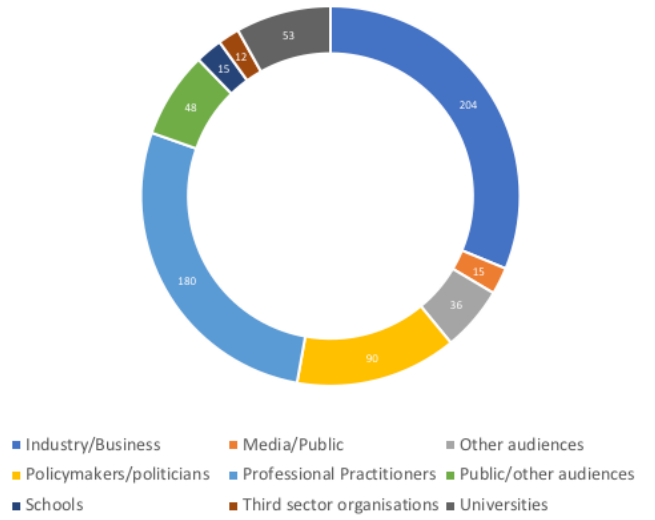

Figure 6 – Audiences of PETRAS Events

PETRAS began life in February 2016 with 47 founding partners who wrote letters of financial support to back the creation of the hub. In subsequent years, the hub was joined by other organisations who came in as (a) partners to the programme such as the Lloyd's Register Foundation and GCHQ, (b) formal partners in response to specific research project funding calls (Strategic Research Fund 1&2 and Partnership Research Fund) and (c) organisations who supported the programme informally such as the European Medical Information Framework.

The table below shows the breakdown of these partners by number of organisations and also through the amount each category contributed towards the hub's industry match funding targets. What is clear is the importance of building a framework of organisations that support the hub in different ways and that PETRAS was able to consistently generate positive returns from its partners throughout the course of its

life and through the different calls that it issued and the objectives that it undertook.

Type	Companies	% Match funding
Founding Partners	47	38.8 %
Programme Partners	14	25.1 %
SRF/PRF Project Partners	36	27.7 %
Programme Supporter	22	8.4 %
PETRAS Partners	**119**	**100.0 %**

Table 1 – The PETRAS ecosystem of partners evaluated by type of partner and percentage of income generated.

PETRAS was conceived with five relatively crude sector classifications or constellations as they were named: Ambient Environments, Supply and Control Systems, Infrastructure, Healthcare and, Transport and Mobility. All PETRAS projects were assigned to one of these constellations depending upon the nature of the project's remit and the amount of income generated from each of these sources is represented in the pie chart below (Figure 7).

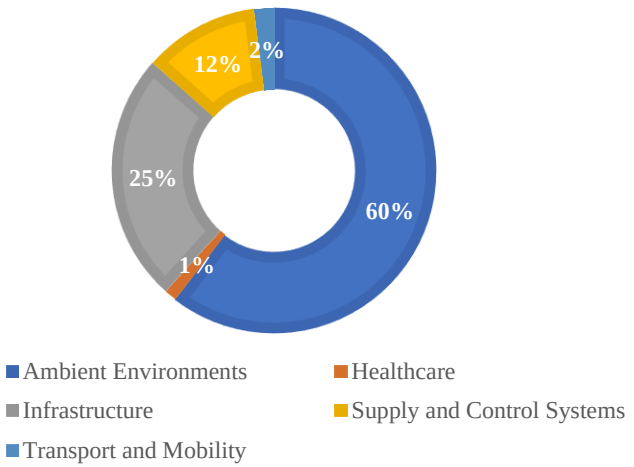

Figure 7: PETRAS constellations by match income generated

Due to the simplicity of the constellations, the information is not particularly useful as the crudeness of classification renders many projects into the ambient environment constellation despite ranging from looking at computer programming to network security to the value of transactions in public spaces. As a result, this paper has sought to evolve a further level of granularity to this information by overlaying official Standard Industry Classification (SIC) code data as provided by the UK government's Companies House website to the original classifications (Figure 9). This matching has been done down the 3-digit level of the SIC classification that is industry group of which the classifications lists 88 in total. It is worth noting that the classification itself goes down to five figures with each additional figure providing a further level of detail, there are 615 of these 5 figure industry classes.
What this data shows is that when more granularity is provided that the projects that PETRAS has managed are focussed on a relatively small number of classifications which are dominated either by themes related to information security or the manipulation of data. That is opposed to those targeted at industry sectors, thus it appears to be more research, rather than outcome based.

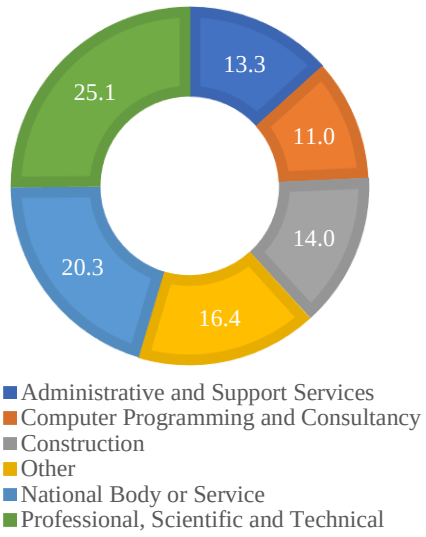

Figure 8 – PETRAS hub broken down by SIC classification and % of total income generated.

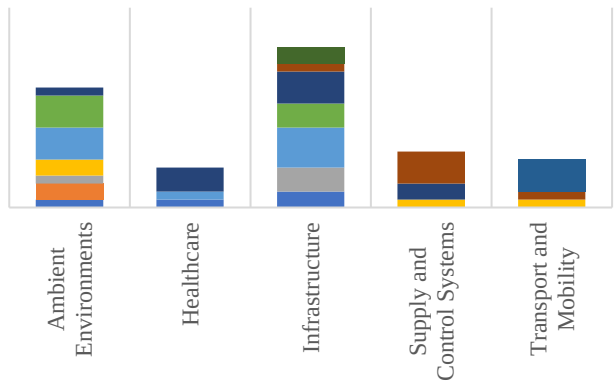

Figure 9: PETRAS by constellation and SIC classification.

It is hoped that providing this greater level of detail into the makeup of the PETRAS innovation ecosystem that future projects of a similar nature might be better able to target those organisations which are in SIC sectors which will be of greatest help to their future. In broad terms this paper has found that a majority of projects can be either split into those that aimed to work with the Internet of Things and its data and information (43%) or those seeking to manipulate it (36%).
To provide added detail, the 119 companies that have partnered to PETRAS have also been mapped against SIC classifications and this data has been mapped against the amount of money that has been drawn in from each SIC (Figured 8). This additional data on the value derived by SIC classification serves to provide further insight into the kind of company which is interested in partnering with research hubs of this nature with the largest groups being those classified as Professional, Scientific and Technical that is often those who engage with IoT research, National Bodies or Services who support that research work such as the Lloyd's Register Foundation and those engaged with Computer Programming

and Consultancy or Administration and Support Services. It is also evident that whilst considerable interest is shown by those organisations seeking to exploit the Internet of Things, this does not as readily transform info a financial investment.

Thus far this economic evaluation of PETRAS has focussed on those projects and partners contained within the hub and so are readily classified and for which granular data can easily be determined. If one steps outside of the hub then the data that is available is less easy to examine but can still be considered to some extent.

PETRAS is closely associated with a number of projects which can be considered aligned that is there is extensive interaction between the programs with benefits flowing in both directions to projects. The clearest of these is the wider IoTUK program which PETRAS sat within. IoTUK included £9.7m of DCMS funding which went directly to PETRAS as well as £10.7m of InnovateUK money to fund Manchester's CityVerve Smart City program, £6.0m of NHS money to fund 2 NHS test beds on dementia and diabetes and £4.9m of funding to the Digital Catapult to facilitate interaction between the diverse elements of the program.

Beyond those programs which sit directly within the IoTUK sphere, there are also further programs which can be considered aligned of which the most notable are EPSRC's Academic Centre of Excellence program which has been awarded to all 11 universities within PETRAS and the Alan Turing Institute (ATI) for Data Science and Artificial Intelligence where around 40 academics that have worked on the PETRAS program have also held positions, mostly fellowships. These additional programs and their alignment demonstrate yet another dimension of wider ecosystem around PETRAS.

We can also consider the wider industrial engagement that PETRAS has undertaken with partners on a more informal basis such as companies who have joined events or made business enquiries into how they might interact with the programme and so have generated a small return in match funding for the hub that is their time supporting the program without becoming a formal partner. Over the course of three years, PETRAS has engaged with around a further 105 organisations beyond its 119 formal partners.

Finally, to draw things together, this wider ecosystem of PETRAS was evaluated by the data science company Jaywing as part of IoTUK's IoT Nation 2018 report. That report looks at the links that are formed between companies and is able to establish that "the PETRAS project is connected to over 1,100 limited companies in the UK. Whilst not all these organisations are explicitly connected to the Internet of Things sector, they are part of business networks that contain IoT businesses allowing for the diffusion of ideas, innovations and collaboration over time."

Further work to analyse this wider network would certainly reveal that whilst PETRAS as a hub provides value and contributes back to the UK economy that funded it, it is the wider innovation ecosystem and its ongoing legacy that will provide greater returns. It is perhaps too early to truly evaluate but with the first PETRAS programme drawing to a close, it should be possible to evaluate this in the near future.

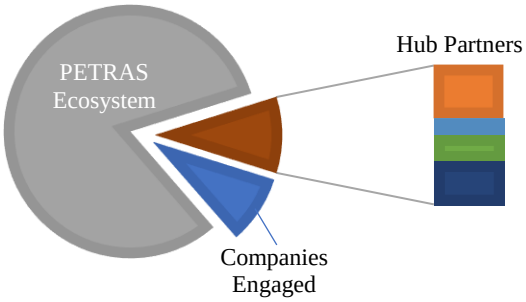

Figure 10: PETRAS Ecosystem by organisations engaged

5. Innovation and Impact Evaluation Framework – Key findings

In this section we present some key findings that resulted from the evaluation exercise done for the PETRAS Research Hub. The complete Innovation and Impact Evaluation Framework for PETRAS is published in the Annex at the end of this paper. The first finding is that inputs alone do not create significant outputs unless a set of intended activities is planned and facilitated. The creation of a community that generates impactful outputs requires a significant investment in time and facilitation, this is especially true for PETRAS where multi-disciplinary academic teams came together for the first time and needed to develop a common language and common scientific methodologies.

A further finding is that innovation, co-creation and augmentation only happens when both academic community and industry players have a common goal and share a common vision in terms of the output of the research activities. Lack of alignment amongst ecosystems participants can lead to a stagnation of innovation. Similarly important is the right balance between the processes layer and the other two layers, research innovation and social-technical impact. The processes layer should be an enabler and facilitator of the other two layers and whenever processes are put in place that do not contribute to the maximization of outputs in the other layers, adoption and compliance will be limited. Lastly, ecosystems are made with people and for people, so continuous mechanisms that address motivation, renovation and evolution should be built in the framework of the programme.

6. Conclusion

This paper contributes to the better understanding of how successful innovation ecosystems are created, managed and evaluated, it builds on the experience gathered from the PETRAS IoT Research hub – a unique Innovation Ecosystem in the Internet of Things domain comprising social and technical researchers; academic, industry and public sector organisations whilst covering technology readiness levels (TRL) from basic principles and technology concepts to system prototype demonstrations and operational deployment. An extensive and complete evaluation of the PETRAS Research Hub is presented in an Innovation and Impact Evaluation Framework. These findings will enable policy makers and research leaders to better understand how to design and facilitate innovation ecosystems in emerging technologies

and what innovation strategies and policies should be put in place [9].

7. Acknowledgements

The authors of this paper would like to acknowledge the PETRAS National Internet of Things Research Hub as the focus of the research. The PETRAS research hub is funded under EPSRC grant number EP/N02334X/1 held at University College London and EPSRC grant number EP/N02298X/1 held at University of Warwick. Special thanks to Jeremy Watson, Jane Butler, Nigel Titchener-Hooker, Aastha Madaan and Robert Thompson for their comments and suggestions.

8. References

[1] HM Government. (2017). Industrial strategy: Building a Britain fit for the future.

[2] 'CISCO – Challenges breakthroughs and best practices' https://connectedfutures.cisco.com/report/internet-of-things-challenges-breakthroughs-and-best-practices/

[3.1]Innovate UK Evaluation Framework - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/681741/17.3253_Innovate_UK_Evaluation_Framework_RatherNiceDesign_V2_FINAL_WEB.pdf

[3] Madaan, A., Nurse, J., De Roure, D., O'Hara, K., Hall, W., & Creese, S. (2018). A Storm in an IoT Cup: The Emergence of Cyber-Physical Social Machines. *Available at SSRN 3250383*.

[4] Jackson, D. J. (2011). What is an innovation ecosystem. *National Science Foundation*, *1*.

[4.1] ComPaTrIoTS call https://epsrc.ukri.org/funding/calls/compatriotsresearchhub/

[5] Carayannis, E. G., & Campbell, D. F. (2009). 'Mode 3'and'Quadruple Helix': toward a 21st century fractal innovation ecosystem. *International journal of technology management*, *46*(3-4), 201-234.

[6] Allas, T. (2014). Insights from international benchmarking of the UK science and innovation system. Department for Business Innovation & Skills (BIS) Analysis Paper, 3, 19.

[7] 'IoTUK – IoT Nation Report 2018' https://iotuk.org.uk/wp-content/uploads/2018/03/iot-report-march2018.pdf

[8] Traitler, H., Watzke, H. J., & Saguy, I. S. (2011). Reinventing R&D in an open innovation ecosystem. *Journal of food science*, *76*(2), R62-R68.

[9] Adner, R. (2006). Match your innovation strategy to your innovation ecosystem. *Harvard business review*, *84*(4), 98.

9. Annex: The Impact Evaluation Framework for the PETRAS research programme.

Inputs	Activities	Outputs	Outcomes	Impact - Short term	Impact - Long term
PETRAS EPSRC funding £9.8M	Formation of Programme Management Team (weekly meetings) Steering Board Meetings (9) Operations Group Meetings (30)	Formation of Virtual Team with IoTUK	Improved governance of IoT initiatives in the UK	Largest research hub with a focus on delivering research to real- world industry partners in the area of IoT and cybersecurity formed.	Delivery of tangible, actual co- created impactful and cross- sectoral technological and socio- economic benefit
	Recruitment of Impact Team Creation of Impact and Comms Board (12) Activation of PETRAS academics network Engagement with founding industry partners	First Living in the Internet of Things/IE conference and IoTUK Summit - LIoT 2018	Exhibition of academic and industry-academic collaboration based research projects, outputs and work in progress. Networking and engagement with new research partners and new government and industry partners.	Potential new collaborators identified both within the academic, and industry. Silos of IoT research integrated within the PETRAS programme.	Establishment of a recognised forum for IoT research in the UK, where researchers present engaging over 200 participants and more than 80 authors
		266 International events, 296 national events, 51 regional events and 42 local events	International engagement with other IoT initiatives and other related technology forums.	Improved reputation of UK IoT-related academic research: UK regarded as international centre of excellence	Position UK as world-leader in expertise and deployment of trusted IoT Technology

Inputs	Activities	Outputs	Outcomes	Impact - Short term	Impact - Long term
PETRAS EPSRC funding £9.8M	Recruitment of Impact Team Creation of Impact and Comms Board (12 meetings) Activation of PETRAS academics network Engagement with founding partners	First Living in the Internet of Things/IE conference and IoTUK Summit - LIoT 2018	Exhibition of academic and industry-academic collaboration based research projects, outputs and work in progress. Networking and engagement with new research partners and new government and industry partners.	Potential new collaborators identified both within the academic, and industry. Silos of IoT research integrated within the PETRAS programme.	Establishment of a recognised forum for IoT research in the UK, where researchers present engaging over 200 participants and more than 80 authors
		266 International events, 296 national events, 51 regional events and 42 local events	International engagement with other IoT initiatives and other related technology forums.	Improved reputation of UK IoT-related academic research: UK regarded as international centre of excellence	Position UK as world-leader in expertise and deployment of trusted IoT Technology
		Launch of PETRAS journal	PETRAS LIoT/IET Journal	A series of reference of high quality applied and innovative research for trusted IoT.	Establishes authority of the UK IoT cohort at par with the EU initiatives.
		User-Research Board workshops (8) 58 Partnerships	Secondments of PhD students; researchers; Co-creation of tasks within research projects that can be directly shaped into policies, software and testbeds.	High recognition of researchers from the PETRAS hub; research delivered to the companies and adapted to real-world applications.	Job-creation for researchers for post-PETRAS era, high impact academia-industry collaboration models for data and technological innovation

Inputs	Activities	Outputs	Outcomes	Impact - Short term	Impact - Long term
PETRAS EPSRC funding £9.8M	Research Outputs Creation of Academic Science Panel	134 Publications from PETRAS 333 PETRAS Related Publications	Creation of Research Knowledge Base for Secure and Trusted IoT	Improved privacy, ethics, trust, reliability, acceptability and security relating to IoT applications in the UK available for public dissemination	Public dissemination of research outputs, conceptual work behind the demonstrators for public engagement.
	Engagement Activities (public, academic, industrial, governmental)	Organisation and/or participation in different engagement activities - workshops, conferences, group expert meetings.	653 engagement activities (255 talks, 243 workshops, 126 expert group meetings, amongst others)	Research Innovation methodologies emerge for socio-technical, economic impact of research.	Creation of a social platform for innovation and co-creation with users and Stakeholders
	Engagement with various sectors of government through research innovation activities	Participation in advisory Committees, citations in policy documents, given evidence to government reviews, participation in national consultation (evidence detail in ResearchFish)	Improved standards and interoperability in IoT: Security by Design, IoT Multi-disciplinary Standards Platform, IoTSF Home Architecture Guidelines for secure development and adoption of IoT applications and systems in Healthcare, Smart Building, Critical infrastructures and Smart Industry		

Inputs	Activities	Outputs	Outcomes	Impact - Short term	Impact - Long term
PETRAS EPSRC funding £9.8M	Reports on findings of ethics, trust, privacy, economic and acceptance streams of PETRAS	State of the Art and Gap Analysis Streams Reports – Synthesis PETRAS-RAEng: Internet of Things, realising the potential of a trusted smart world	PETRAS researchers' proposals available to and implemented by policy-makers, particularly central government Policy Framework Design	Early dissemination and reference for policy makers for establishing governance in the IoT sector	Holistic governance for IoT technology for the good of the citizens
	Dissemination of research beyond PETRAS community	Little Books (8) Dissemination Event at Tate Modern Demonstrators Public Events	Translation of PETRAS Research to non-academic audiences	PETRAS 2 Funding - £13M	Creation of an enduring legacy from the PETRAS Hub, beyond the end of the funded period; Easy to read references for non-IoT and non-technical people

Inputs	Activities	Outputs	Outcomes	Impact - Short term	Impact - Long term
University partners funding £4.5M	9 University Partners activate their network	University Partners extended – 11 universities – Bristol and Newcastle	New research areas funded - IoT and Blockchain, Liaison projects with IoTUK Partners, etc	Increased awareness and demonstration of PETRAS issues	Social benefits (health, environmental, social, improved service delivery)
	SRF 1 Call	15 new Research Projects addressing research gaps and emerging research challenges			
	SRF 2 Call	6 new Demonstrator Projects: IoT in the Home (IoTiH); IoT in Transport and Mobility (IoT-TraM); PEDASI; SecCNIoT; MASBI and Art Connect	Integration and Alignment of multiple projects into 6 demonstrators open to all public audiences		

Inputs	Activities	Outputs	Outcomes	Impact - Short term	Impact - Long term
Industry partners funding £9.7M pledged	Industry support and recognition acquired	Match-funding £9.8M 224 Engaged Organisations	Significant Economic augmentation from initial funding	PETRAS 2 Demonstrators Funding - £10M	Creation of a trusted model for industry-academia collaboration
47 Founding Industry Partners 10 Research Streams 17 Academics	PRF Call	15 partnership projects	Increased IoT-related research and development in the UK	Increased UK competitiveness and reputation within IoT markets	
	Thematic Workshops	Research Requirements alignment with funders, stakeholders and partners	New IoT applications developed (BitBarista, Polly, SEMIOT, etc)		
		Stakeholder support with financial commitment	Co-creation and Design Fiction Methodologies used in practice		Creation of a cross-disciplinary language and framework across research domains, industries, and government departments
21 Research projects	Co-creation activities with industry partners - engagement looking at new research areas	119 Industry Partners 120 Academics 51 Research projects 6 Demonstrator Projects	Increased collaboration between PETRAS institutions and between PETRAS and private, public and voluntary sector partners (over 1100 connections - IoT Nation report)		