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A Comparative Analysis of Energy And Health Sector Firm R&D Activity in Wales

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ABSTRACT

Given the current levels and future requirements of R&D in Wales this paper focuses on the Welsh Government (WG) priority areas of energy and health sector firms. In the light of current knowledge of R&D levels it considers: (i) the future requirements of R&D in Wales in terms of economic strategies and industrial trends, and (ii) the specific R&D needs of the energy and health sectors for the development of research policy for Wales. To facilitate this, the research draws on a number of research methods, including secondary data analysis and surveys. It appears that there is a need for selectivity and concentration of resources into those sectors such as energy and health where Wales has a critical mass of research and resources which have the potential for development at a World class level. The current levels of research activity in these areas can be increased if the right R&D decisions are made. In relation to this potential there are certain R&D requirements in these sectors that need to be met. These are reported in the research findings of the study undertaken into the energy and health sectors described in this paper.

Keywords: research; development; management; policy; energy; health

INTRODUCTION

The efficiency of the research policy making process in a modern economy such as Wales will be influenced by its mode of functioning. In this context science policy will be one of several inter-related activities that will be the concern of Welsh Government (WG) policy making. Activities of national importance include agriculture, economy, education, energy, environment, industry and social welfare, for example. In this inter-relationship science will have common interests with these activities. Examples are those with education regarding school, college and university curricula, health with medical research and industry through the development of new processes and products (Dunkelman, 1976). Science policy has been defined as:

"policy for science (covering issues such as funding of university research, intellectual property rights for scientific and education policy) and public policy issues with a scientific aspect (e.g. GM plants, climate change, biological weapons)" (The Royal Society, 2007).

The relationship between science and other activities can be seen as both a cost and a benefit. Indeed, the development of a new process or product grounded in technology or science may have a number consequences in terms of economic activity (job creation, intellectual property, international trade, etc). The interaction of science with government will not only involve negative and positive relationships but may also be conflicting and co-operative. There will be a web of competition for programmes, initiatives, funds, personnel and prestige. Government members, civil servants, consultants and other individual and corporate interests will compete for these activities. Resource allocation problems and organisational structure will be at the centre of Welsh governmental policy making. Discussion about science policy making may never resolve problems but will be part of the policy making process.

Although the activity of science policy making involves 'science' it also embodies 'technology' since science and technology are closely connected. When science moves into the realm of the decision-making machinery of government it is affected by the usual political pressures, passions and motives. These may be well intentioned or not but the common denominator will be political viability of the science policy decisions made. With the diversity and complexity of scientific activities there will be considerable difficulty in trying to resolve a number of related problems. Two problems that will be of paramount importance to the Welsh Government will be what policies will be required to guide the scientific and technological research and development (R&D) efforts of the Welsh economy and how they will organise decision-making, implementation, co-ordination, evaluation and funding of science policy programmes and initiatives. With regard to R&D activity in Wales two sectors that have been identified as being of crucial importance to the future of Wales are those of energy and health.

The consultation paper and report "A Science Policy for Wales?" (WAG 2006a&b) defines three main strands of a future science policy as "health developments including

public health, tele-medicine and links to demographic change and epidemiology, low-carbon energy systems, and enabling sustained economic and social renewal (utilising both natural and social sciences expertise)" (WAG 2006a&b).

Since the consultation paper and report in 2006 the Welsh Government established the Science Advisory Council for Wales (WG, 2010), comprising internationally recognised academics, experts and scientists, tasked with assisting in developing science policy for Wales. The independent council considered a preliminary draft policy in early 2011. With regard to this the Deputy Minister for Science, Innovation and Skills, in her address to the Council's inaugural meeting on Wednesday, 1 December 2010, outlined the challenges facing Wales including the need to raise the research performance in Wales to boost research and development income (WG, 2010). Further policy considerations with regard to innovation, research and development in Wales have considered foundations for the future by building on strengths and opportunities in terms of the life sciences and health, low carbon, energy and environment, advanced engineering and materials and ICT and the digital economy (WG, 2014). Following this a vision for "Research and Innovation in Wales" (NAW, 2019) has been made with recognition that investment will be needed for more innovation from cutting edge research. More recently, "Scoping the future of Innovation Policy in Wales" (Delbridge, Henderson and Morgan, 2021) proposes a new innovation policy agenda for Wales, taking into account the impacts of Brexit and Covid, and based on the six recommendations of 1: a new innovation strategy for Wales, 2. encouraging universities to develop their traditional research activities, 3. investment in the skills, capabilities and resources to support innovation, 4. greater capacity for mission-oriented innovation, 5. coordination of place-based investment plans, and 6. innovation policy agenda should be brought into the centre of Welsh Government.

The research question considered in this paper, pertinent to the proposition for science policy in Wales, is "what is the capacity of Wales to become a World leader through the exploitation of R&D activities in both academia and industry". Therefore, given the current levels and future requirements of R&D in Wales this study focuses on the Welsh Government science policy priority areas of the energy (Thomas et al., 2020) and health (Thomas et al., 2021) sectors. In the light of current knowledge of R&D levels it considers:

- The future requirements of R&D work in Wales in terms of economic strategies and industrial trends.
- The specific R&D needs of the energy and health sectors for the development of a science policy for Wales.

To facilitate this, the paper draws on a number of research methods, including secondary data analysis and surveys.

MANAGING R&D AT A NATIONAL LEVEL

When R&D statistics for the United Kingdom (UK) are considered it is apparent that the two smallest areas in terms of R&D activity are Wales and Northern Ireland. There is therefore the argument that R&D should be developed in these areas and funding into university research should create increased prosperity and wealth for the Welsh economy (Jones-Evans, 2006). Statistics reveal that 1.8% of UK business R&D is carried out in Wales (ONS, 2021) and although this has improved in recent years there is a need to encourage Welsh enterprises to undertake research and to attract business projects that spend a high percentage of turnover on R&D (Jones-Evans, 2006). Figure 1 shows R&D expenditure in Wales for the years 2006 to 2019.

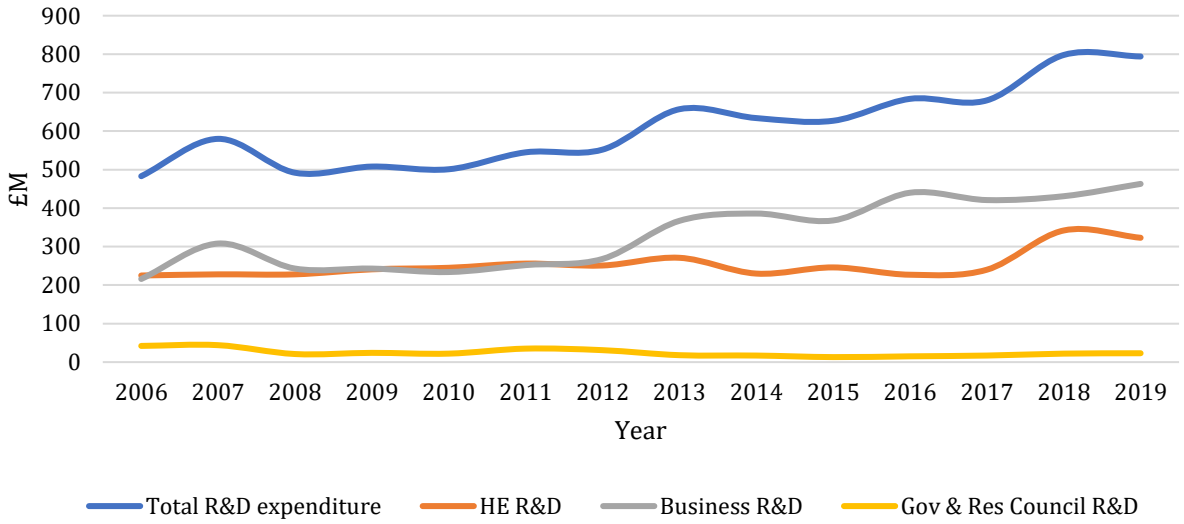


FIGURE 1: R&D expenditure in Wales
Source: StatsWales (2020)

R&D expenditure in Wales showed a rise from 2006 to 2007 followed by a fall from 2007 to 2008 with an upward trend in most years from 2009 to 2019, and a levelling off in 2019. Business R&D expenditure was the best performing compared to HE R&D followed by Government and Research Council R&D expenditure although HE R&D was higher than Business R&D in 2006, 2010 and 2011 (StatsWales, 2020).

Although the UK Government has increased the level of tax breaks for companies to carry out R&D it is argued that the Welsh Government, under legislative powers, can offer incentives for companies to spend on R&D in Wales especially in key sectors such as energy and health (encouragement of innovative business in Wales depends on the research base) (Jones-Evans, 2006).

The approach to the assessment of R&D activity in this paper has been to focus down from the national (macro) level of science policy making to consider the energy and health sectors at the regional level (meso) and the individual business level (micro). This has involved considering science policy making for Wales concerning the energy and health sectors as two of the main strands and R&D work as one of the principal elements. The literature review has revealed the major concepts involved in the study of R&D in industrial sectors and the questionnaire(s) developed and tested through a pilot study have been used to survey companies in these sectors. The main findings are discussed in the conclusions.

The research is both of academic and practical significance, contributing to the body of understanding on the current levels and future requirements of R&D in Wales, as well as the level of R&D in the Welsh Government science policy priority areas of energy and health. With regard to these priority areas, and the assessment of sectoral capacity and research expertise in Wales, the Welsh Government originally endorsed the five main areas: ICT, New Media, Low Carbon Economy, Advanced Manufacturing, and Health Care and Biosciences.

As well as these sectors being identified as areas for the development of the commercialisation of R&D in Wales other sectors would still be supported in the future such as Tourism. The importance of enhancing the links between business and academia to benefit these areas of Wales would involve an analytical approach by the Welsh Government to develop complementary strengths between business and academic expertise. Together with examples of "good practice" an effective strategy is required to support plans to progress the Welsh Government agenda for improved competitiveness and innovation (IoD, 2010).

The Welsh Government announced a radical transformation in the way the Welsh economy would be supported (WAG, 2010). As a result, it was going to support industry-led investment in six key sectors, where there was a clear advantage for Wales. Target sectors for Wales were: Creative industries, ICT, Energy and Environment, Advanced Material and manufacturing, Life Sciences, and Financial and Professional services. This was similar to previous priorities with the addition of the target sector of Financial and Professional services.

With regard to priority areas an understanding of the micro level of R&D activity can result in more efficient policy initiatives. In particular, the focus on examining good practice could result in an effective 'benchmarking' exercise that will benefit policy-makers in Wales. It may be possible, from the results of this research, for support organisations to develop programmes of assistance that are specifically targeted towards increasing the efficiency of the R&D function for indigenous small firms in Wales with limited or developing R&D capacity.

ENERGY BUSINESS SECTOR

The energy business sector in Wales makes a significant contribution to Wales' economic growth and employment. Wales has an established private sector energy base which includes nuclear, wind, hydro, gas and coal. This has involved large companies such as BHP Billiton, EoN, RWE, Exxon and GE which have had plants in Wales. Unfortunately, these companies tend not to have R&D departments located within the Principality. There is also the development of Milford Haven as a liquid natural gas import terminal and associated gas fired electricity power generation. A considerable proportion of the industrial base of Wales is focused on large power generation and usage. Due to this it is affected by changes to the economics of energy and the technology base. As a consequence, there is an incentive for companies to lead the development of energy processes. In the photovoltaics manufacturing sector Wales has had companies such as Sharp in Wrexham and G24 in Cardiff together with companies in the associated supply chain. There is also a solid-state lighting industry consortium and companies in micro generation development and installation and electronics related operations. In order to help these companies, there have been WG support mechanisms involving programmes such as KEF, SMARTCymru and CETICs. These promote commercial exploitation and industrial collaboration with the university science base. There has also been funding for the energy business sector through European funds in the past. These included support for a gas-turbine test facility, the Welsh Energy Research Centre (WERC), MCT (tidal power) and Wave Dragon (wave power). Opportunities have been identified by International Business Wales for inward investment in the sector. One of the advantages for large companies is skills availability in the industrial technological R&D work and HEI sector. Long term energy strategic objectives and technology opportunities have involved industrial research.

HEALTH BUSINESS SECTOR

Complex challenges need to be met for effective mechanisms to be developed between the health business sector, innovators, the National Health Service (NHS) and individuals. In relation to this four key themes were identified in a review of bioscience in Wales (Ernst Young, 2003) and these were building the science base, innovation and commercialisation, critical mass and unified leadership. This is appropriate to the research spectrum involving basic research through to translational research. Two hundred and ninety companies active in bioscience were identified in the review and these included drug discovery technologies and systems, non-invasive surgery, diagnostics (in vivo and in vitro), medical devices, clinical trials and pharmaceuticals. It recognised the need for research collaborations which are multidisciplinary when appropriate and for there to be active partnerships between industry, academia and the NHS. This is highlighted by clinical research where to meet the needs of industry there is a need to move towards a single system that delivers quality and rapid access at reasonable costs (McKinsey, 2005). In order to build collaborations in bioscience the MediWales industry network was established. There are also NHS networks provided by WG's health professional advisory committees. It is believed that these could work together to determine potential clinical collaborations within the NHS in Wales to provide access points for industry. For the commercialisation of ideas partnerships between industry, HE and the NHS can generate income of benefit to research through reinvestment. There are also links with the devices industries through MediWales and the pharmaceutical industry through the Association of the British Pharmaceutical Industry (ABPI) Welsh Industry Group. It is therefore possible to develop existing strengths in the health business sector through collaboration across businesses and organisations to share facilities, expertise and best practice.

R&D LITERATURE REVIEW

This literature review considers Research and Development (R&D) in terms of spillovers and technology absorption. According to Revesz and Boldeman (2006) the economic reason for governments to support R&D management is based upon the externalities (spillovers) caused by R&D which has received much interest in innovation literature.

Further to this two roles for R&D suggested by Griffith et al (2004) are to stimulate innovation and to create an understanding of discoveries by others which to the originating firm are confidential. To all intents and purposes Wales is an "open economy" and a major policy question concerning R&D will be the extent to which indigenous technology progress is created by local R&D or by developments globally (Revesz and Boldeman, 2006) including outsourcing (Hsuan and Mahnke, 2011; Ambos and Ambos, 2011). It must be borne in mind that economic growth can be created through assimilated disembodied knowledge (education, learning, R&D, knowledge systems and economic reform) contrary to the embodiment of technology innovations in imports (DCITA, 2005). The economic impact of R&D on the Welsh economy is therefore of importance.

It has already been recognised that the technological development of indigenous enterprises in Wales is influenced by various sources of know-how including R&D, industry contacts, learning, ICT and publications, for example (WAG, 1998). R&D is therefore a major source for technological progress in the modern Welsh economy. A principal justification for WG support of R&D policy activities will rest upon the positive spillovers which are the positive externalities from R&D (Revesz and Boldeman, 2006).

The Schumpeterian hypothesis (1934; 1942) suggests market concentration and large production units for R&D intensive industries are not necessarily confirmed through empirical evidence. Whereas in R&D intensive industries there will be a tendency to industrial concentration at a global level (small firms will exist as suppliers of components and as "niche" product competitors), in other R&D intensive industries there will be numerous small enterprises of niche products (Revesz and Boldman, 2006). The process of "creative destruction" (Schumpeter, 1934; 1942) means that enterprises in technology dynamic industries, where there is oligopolistic competition, will need to innovate to maintain their position in the market. Caballero and Jaffe (1993) have provided empirical support for this hypothesis and according to Nelson (1990) the views of R&D and company managers also support this point.

A small nation like Wales will receive most of its technology innovations from other countries and with competitive conditions indigenous small and medium-sized enterprises (SMEs) will have the incentive to adopt exogenous new technologies without WG support. In particular, on a qualitative basis there will be the case both pro and ante for R&D government support and quantitative analysis will be required in order to determine R&D subsidies at an optimum level (Revesz and Boldeman, 2006).

Whereas scientific knowledge (mostly public sector R&D) which contributes to greater understanding instead of new applications in the public domain is more available know-how and technical information ("proprietary" knowledge) tends not to be publicised and surveys of R&D and business managers have supported this view that patent disclosures and technical publications do not play a significant role in the provision of technology information to innovative enterprises (Revesz and Boldeman, 2006). Indeed, a survey in the United States by Schuchman (1981) found that engineers involved with new technologies relied on in-house expertise and talking to colleagues for information that was relevant and they tended not to use technical publications. Further to this, Taylor and Silbertson (1973) considered how much R&D managers in the UK would pay if access to abstracts and patent records was denied.

According to Griffith et al (2004), two roles for R&D are those of (i) stimulating innovation and (ii) enabling understanding and the imitation of discoveries which remain confidential by other originating firms. R&D therefore plays an important role for the development of an "absorptive capacity" and is equally critical for technology transfer and innovation (Revesz and Boldeman, 2006). Econometric evidence concerning the importance of the "two faces of R&D" are also presented by Griffith et al (2004) through the examination of productivity growth in industries for 12 OECD economies. R&D appears to stimulate innovation indirectly by technology transfer or directly by those involved with leading edge technology frontiers (Revesz and Boldeman, 2006). Further, it is suggested that R&D plays a crucial role in multi factor productivity levels for industries in OECD countries (Griffith et al, 2004). Cohen and Levinthal (1989; 1990) have provided a similar view about the importance of R&D in nurturing both learning and innovation. In particular the importance of R&D in enhancing technology absorption is considered important for small open economies such as Wales.

Public support schemes for R&D activities, although very often exhibiting problems, can be run with an acceptable level of difficulties and these can include subsidies for business R&D, research by public bodies (especially universities) and IP protection (Revesz and Boldeman, 2006). The level of government support for innovation can be difficult to gauge especially since there is limited information on R&D activity and there may be a number of policy options (Scotchmer, 2004).

Although there appears to be no data on the commercial return from R&D activities, case studies of firm managers show that they will invest in R&D due to competitor's technology advances and the fear of being out of business (Revesz and Boldeman, 2006). In a study by Revesz and Lattimore (2001) no statistical positive significance between R&D intensity and firm profitability was found and a survey by Jaruzelski et al (2005) also found no direct relationship between R&D spending and corporate success. It is generally agreed that at international and national levels R&D spillovers are considerable and are many times greater than private returns (Lederman and Maloney, 2003; Sena, 2004). Studies on the economic impact of R&D have focused on the rate of return for business R&D at national levels (Maddock, 2002; Shanks and Zheng, 2006).

Whereas Lederman and Maloney (2003) found a relationship that was strongly negative for GDP per capita and national R&D intensity Gittleman and Wolff (1998) found that R&D intensity was positively related to the growth of gross domestic product (GDP) in advanced industrialised countries which infers that R&D is advantageous to countries with industries near to the frontiers of leading edge technologies. A significant policy question for R&D activity in a small open economy like Wales is to what extent domestic technology progress is influenced by global developments or domestic R&D (if this is by overseas technology progress there is the argument that there may be little need to foster domestic R&D work).

Further to the Coe and Helpman (1995) model for cross border knowledge spillovers Eaton and Kortum (1996; 1999) considered the flow of ideas from abroad as well as those internally generated. Ideas from a country will depend on R&D sector productivity and size, the technological level, cross country patent applications and the use of these ideas by the country and other countries (Revesz and Boldeman, 2006).

Pottelsberghe and Lichtenberg (2001) developed the Coe and Helpman (1995) model by including R&D stocks related to outward and inward investment in addition to the R&D content of imports. It is apparent that it is not possible to simply import overseas technologies since their application by local enterprises will require investment in learning involving R&D. Hirsch-Kreinsen et al (2005) observe that for medium low and low tech manufacturing firms the main source of innovation will not come from R&D but from other activities involving assimilation and learning such as contact with people in businesses in the same industry, suppliers and customers. It appears that most innovations in more than ninety per cent of an economy, excluding high and medium tech manufacturing, will not be through indigenous R&D (Revesz and Boldeman, 2006).

RESEARCH METHODOLOGY

Introduction

The research was carried out in three stages. Figure 2 below shows, the research strategy aimed to use the most appropriate methodology to address the specific areas of the research.

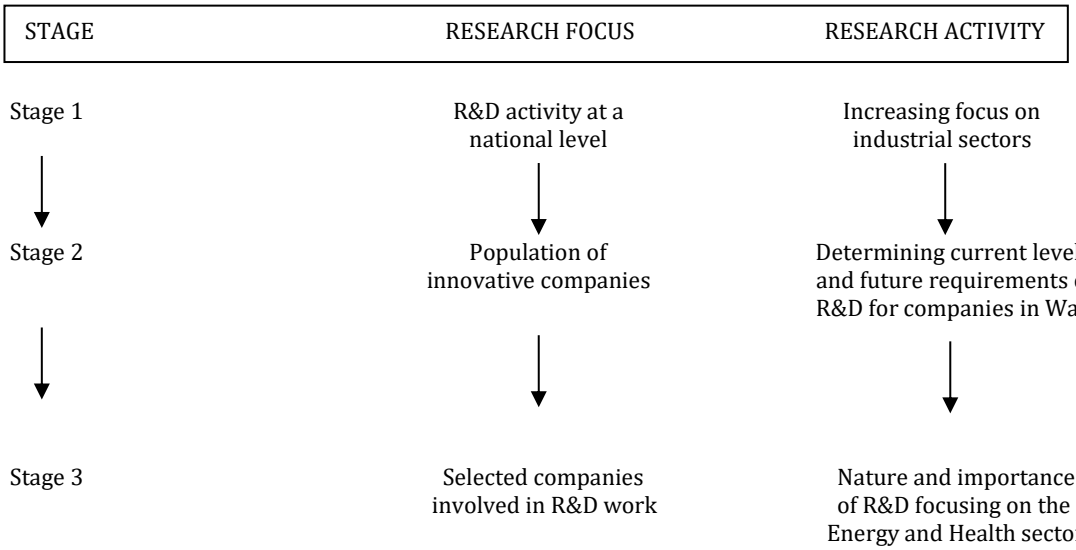


FIGURE 2: Focus of the research study

The study used:

- Secondary data to assess the current levels of R&D in Wales.
- Quantitative methods to determine the level of R&D activity for a sample of firms.
- Semi-structured qualitative methods to examine, in detail, the nature and importance of R&D focusing on the energy and health sectors.

It was one of the primary aims of the study to understand 'good practice' for R&D activity within companies. As stated in the European Action Plan for Innovation (EC, 1996), this approach is important to small firms, as emulation amongst firms enables them to compare themselves with the international leaders in their field and is an effective way of propagating good practice.

Stage 1 – An Assessment of the Current levels of R&D in Wales

This stage set out to assess the current levels of R&D that currently exist in Wales. It has drawn on existing research and secondary data sources. Secondary data sources include existing literature in the area, which consist of both published material and 'grey' literature available (including reports from the European Commission, universities and consultants).

Stage 2 – Questionnaire Survey

This stage consisted of three main sub-tasks. The first established a population of suitable companies, using the guidelines established in Stage 1. SIC codes have been used to classify energy and health firms.

The energy sector firms sampled in the study have been drawn up according to a classification for energy R&D performers (WAC, 2006) according to: Coal technology firms, Nuclear power firms, Oil firms, Liquefied natural gas firms, Wind energy firms, Wave and tidal firms, Biomass firms, Solar energy and photovoltaics firms, Geothermal energy firms, and Hydroelectric power firms. A database of firms based upon the above categories was assembled from a database of companies and supplemented from other information sources available to the study. This provided an appropriate sample of companies for the research survey work to be undertaken.

For the classification of energy R&D performers the definition of "R&D" in the energy context has been determined. Accordingly, energy R&D (EIA, 1999) can be categorised as: 1. Basic energy research - Basic energy research rather than considering particular applications involves advancing scientific knowledge and understanding phenomena. 2. Developing new energy technologies research - This concerns scientific knowledge that is commercially applicable with known objectives involving research uncertainties and difficulties. 3. Improving existing energy technologies research - This encompasses the design and testing of new processes using scientific knowledge involving cost and technical uncertainty with the beneficiaries being operators and customers of the improved technology and producers and consumers of particular fuels.

The three categories above can be related to the energy R&D performers as (a) Basic Energy Research and (b) Applied Research and Development including Coal (1), Nuclear power (2), Other fossil energy – Oil (3), Liquefied natural gas (4), Renewable energy, Wind (5), Wave and tidal (6), Biofuels and Biomass (7), Solar energy and photovoltaics (8), Geothermal (9) and Hydroelectric (10).

The health sector firms sampled in the study have been drawn up according to a classification for health R&D performers including: 1. Biotechnology firms, 2. Pharmaceutical firms, 3. Medical equipment firms (including instrumentation and diagnostic equipment), 4. Health product firms, 5. Alternative health product firms, and 6. Other health firms.

Similar to the energy sector a database of firms based upon the above categories has been assembled from a database of companies and supplemented from other information available to the authors. This again provided an appropriate sample of companies for the research survey work to be undertaken. For the definition of "R&D" in the health context the definitions of R&D and health research R&D used by the OECD have been adopted for the study (OECD, 1994):
"Research and experimental development comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this knowledge to devise new applications."

The definition of "R&D" in the health context is as follows:
"Health research and development is a process for generating systematic knowledge and for testing hypotheses, within the domain of medical and natural sciences as well as social sciences including economics and behavioural science. The information resulting from this process can be used to improve the health of individuals or groups."

The main categories of the classification of health R&D (based on the Global Forum for Health Research) have been followed according to: 1. Non-oriented, fundamental research, 2. Health conditions, disease or injuries (classified by disease), 3. Exposure, risk factors that impact on health (determinants), 4. Health systems research, and 5. Research capacity building.

Therefore the "R&D" definition in the health context is generic and covers a wide range of health activities appropriate to the health sector in Wales.

From this a sample of firms was drawn up which was stratified by sector and size. The establishment of a database enables a longitudinal study of these firms to be developed over a period of time. The second sub-task was the development of the questionnaires. The final part was data collection using the questionnaire developed.

The methodology utilised a postal questionnaire. The mailing of the questionnaire was to one hundred and forty-four energy sector companies and one hundred and ninety-seven health sector companies. The low response rate for the pilot study was not repeated for the full survey due to the questionnaire form being reduced from 6 pages in the Word document format used for the electronic survey in the pilot to 3 pages in the SNAP format in the full survey. Also, named recipients were used in the full survey which was not the case in the pilot. This was followed by data cleaning and input of data. The data gathered was examined quantitatively using the SNAP survey software package.

Stage 3 – Qualitative Analysis
The objective of this study was a detailed qualitative analysis of the issues regarding R&D activity in the industrial sectors in Wales from the analysis carried out in Stage 2.

RESEARCH FINDINGS

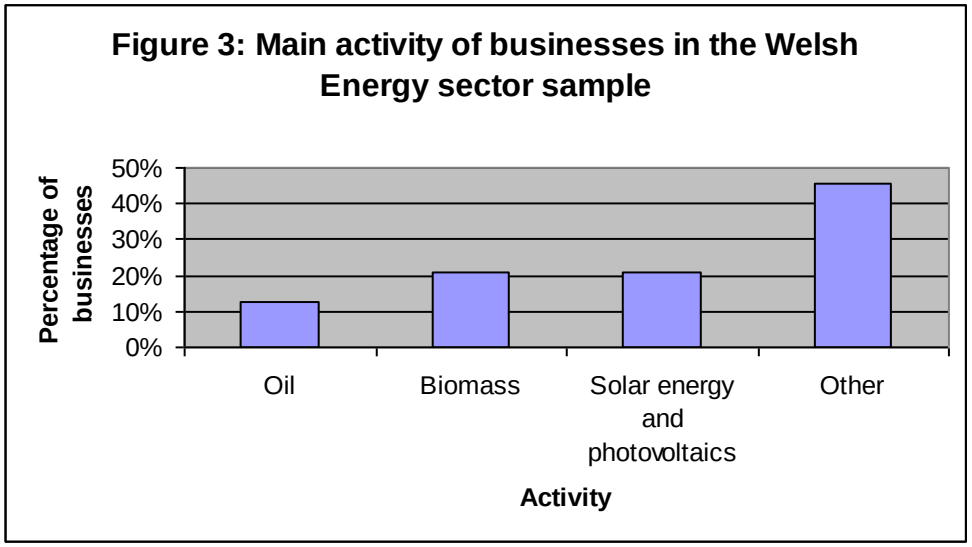
Introduction

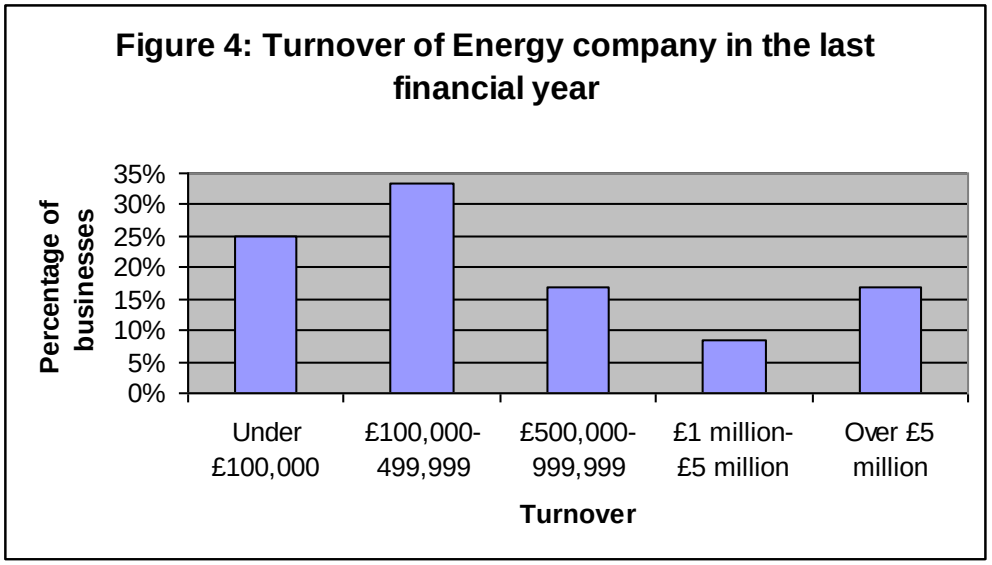
The research findings have been analysed according to the separate surveys undertaken for the energy and health sectors in Wales and then combined to form a comparative analysis. Questionnaires were sent to one hundred and forty-four energy sector companies with twenty-four responding (17%) and one hundred and ninety-seven health sector companies with twenty-nine responding (15%). The response rates were higher for the full survey compared to the pilot survey (energy sector companies 15% and health sector companies 9%) due to a more compact form for the questionnaires and named recipients (as noted in the Research Methodology). Percentages as well as numbers are reported so that a basic comparison can be made between the two sectors. Each sector and the combined analysis are reported below. The three main sections of the questionnaire surveys were general business information, specific factors relating to R&D and additional company observations on aspects of R&D.

Energy sector

- *The business*

The main activities of the businesses in the sample were oil, biomass, solar energy and photovoltaics. Firms were also in other areas and these included renewable energy technologies, bio fuels and bio energy, energy management, wood fuel, water power and electricity generation. Figure 3 shows the main activities of the businesses in the sample.

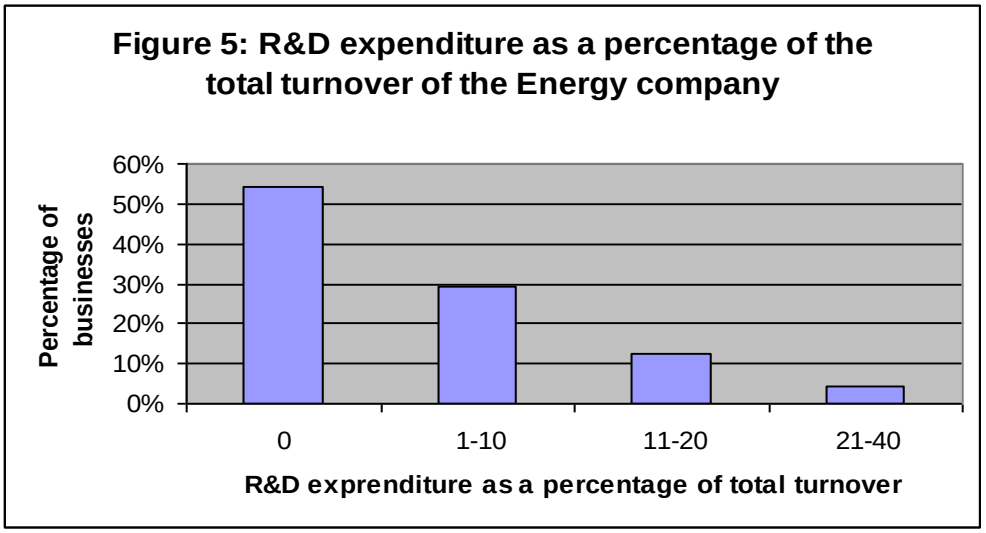




• *Specific factors relating to R&D*

The products/services offered to clients/customers by the energy sector companies included the design and supply of energy systems (solar pv, small hydro, small wind, biomass, wind farm design, environmental impact assessments), renewable energy, supply and installation of solar thermal systems, bio-fuels, electricity generation, professional energy management services, wood fuel, geological and reservoir engineering, energy efficiency products and services and bio-power services equipment and training.

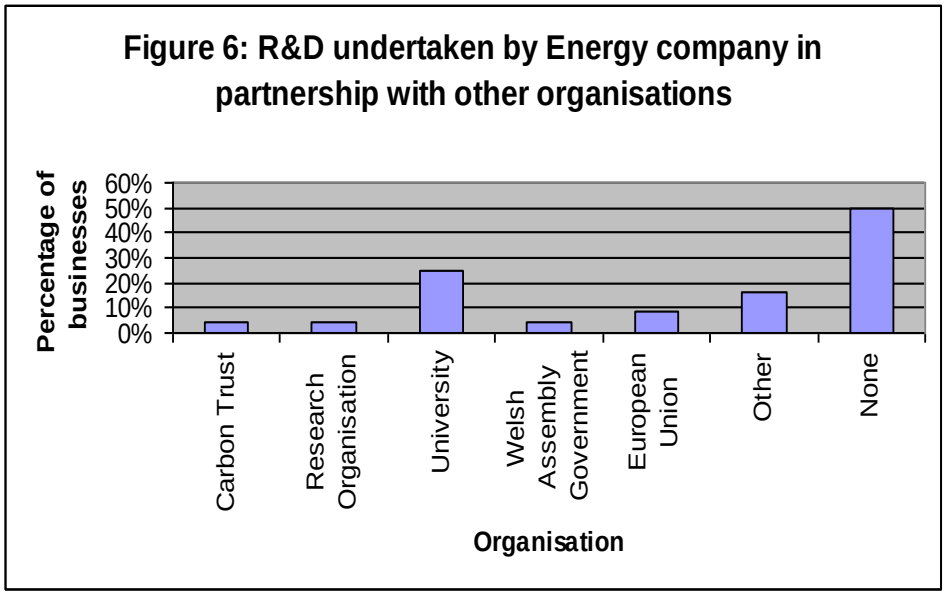
The areas of R&D the businesses were involved in included basic energy research, developing new energy technologies research, improving existing energy technologies research, new energy products, and other which included services and remote monitoring and analysis. Three of the energy companies in Wales had their own dedicated R&D department and fourteen of the companies had no qualified scientists and engineers (QSEs) engaged in R&D in the business, nine had 1-20 QSEs and one company had between 61-80 QSEs. R&D expenditure as a percentage of the total turnover of the business is shown in Figure 5.



Regarding businesses investing in R&D for eight companies investment was increasing, for one it was stable and for three it was decreasing. The main reasons for investment in R&D increasing were that there was a need to be inventive, to have patents on energy systems, to develop ideas, new forms of fuel, higher level service provision and new technologies and products. Reasons for decreasing investment in R&D were concentration on responding to market growth and reliance on grant funding decreasing. When asked whether R&D was essential to the company business model nine firms responded that it was and five that it was not.

Two further companies commented that R&D was something they wished to look at in the future but at the moment there was no budget for it although they had a few ideas and that they considered R&D to be essential in sustaining and developing the business.

A greater percentage of energy businesses reported that the R&D they undertake is market oriented compared to some who commented that they were first developing new technologies/systems/products/services and then the market. Figure 6 shows the percentage of R&D undertaken by energy companies in partnership with other organisations.



Six different categories of organisations were reported by twelve of the companies for R&D undertaken in partnership and these included the Carbon Trust, research organisations, universities, Welsh Government, European Union, other (including work in China, Spain and Greece) and twelve companies commented that they were not working with any organisations. The types of partnership they were involved in were academic research papers (one respondent), Knowledge Transfer Partnerships (KTPs) (four respondents), consultancies (6 respondents) and spin outs (two respondents). Only two companies were in receipt of sponsorship or grant for R&D (the Trans National Leader + programme and CASE) and twenty-two were not.

On a rating of most important to least important the major influences on the commitment to R&D expenditure were reported as the need to remain competitive as the most important, followed by to develop intellectual property (IP), level of support, to develop best technology and tax benefits. The least important influence on the commitment to R&D expenditure was to train staff. Only three companies owned twenty-nine patents (three, twenty-four and two respectively) and three companies had filed for thirty-one patents (six, one and twenty-four respectively) in the last 2 years.

• *Additional company observations on aspects of R&D*

The issues that energy firms felt limited the R&D opportunities of the company were time constraints and insufficient equipment. These were followed by space restrictions, R&D not being a central aim of the company, the current market, no government support and a lack of finance. The least important issues were a limited desire by the company to undertake research, restricted research ideas and inadequate skills. Companies reported that they published their R&D activities through internal reports (five firms), external reports (one firm) and by other means (two firms) (European partner reporting and client partners).

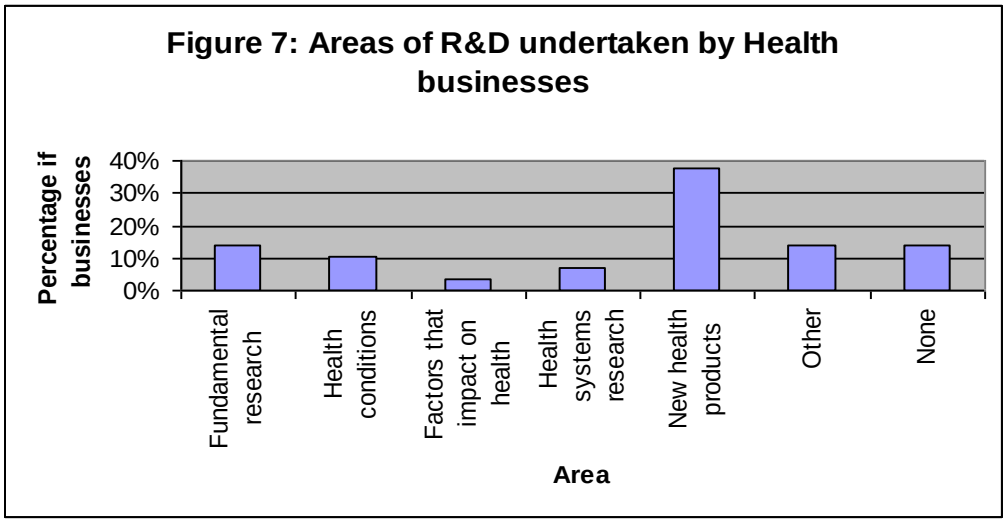
Health sector

• *The business*

The main activities of the businesses in the Welsh Health sector were biotechnology, pharmaceutical, medical equipment and health products. Firms were also in other areas and these included a hybrid business involving biotechnology, pharmaceutical, medical equipment, health and alternative health product activities and other areas including instrumentation, bio chemicals and industrial microbiology.

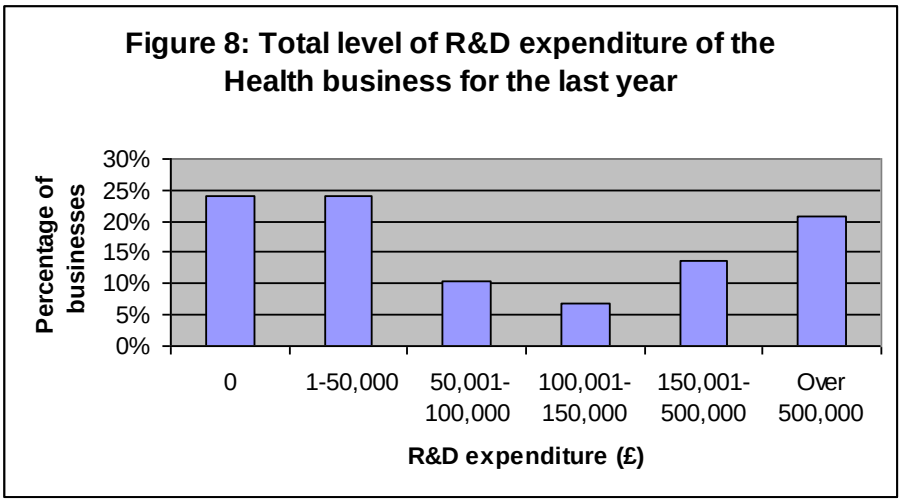
• *Specific factors relating to R&D*

The products/services offered to clients/customers by the health sector companies included the development of medical devices, the improvement of health products and processes, the testing of electro-medical equipment, development and manufacture of wound dressing materials, consultancy services to biotech companies, microbiology test kits, pharmaceutical products, IVD products for monitoring diabetics' health, laboratory incubators and cell processing. The areas of R&D the businesses were involved in are shown in Figure 7.

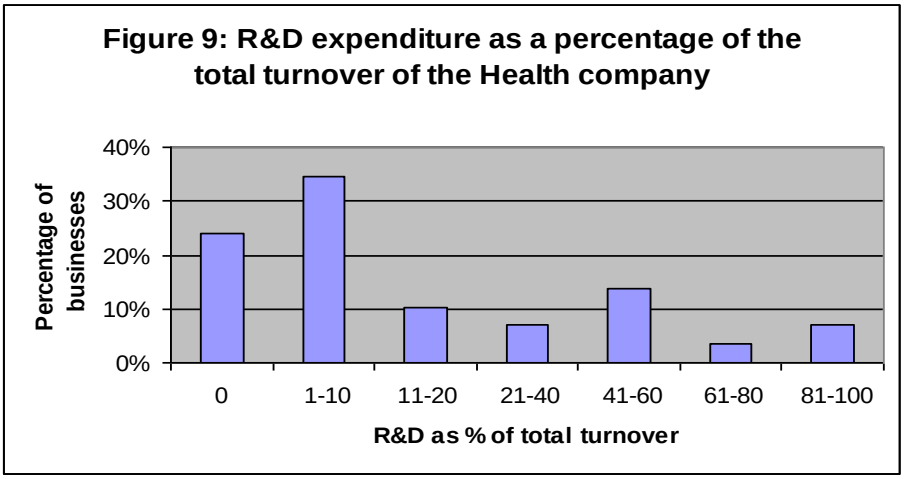


These included fundamental research, health conditions, disease or injuries, exposure, risk factors that impact on health, health systems research, new health products, other health areas including developing new test methods, product development, near market contract R&D and basic research. Fourteen of the companies had a dedicated R&D department.

Six of the companies had no qualified scientists and engineers engaged in R&D in the business, thirteen had 1-20 QSEs, three had 21-40, three had 41-60, one had 61-80 and three companies had between 81-100 QSEs. The total level of R&D expenditure of the businesses for the last financial year is shown in Figure 8.

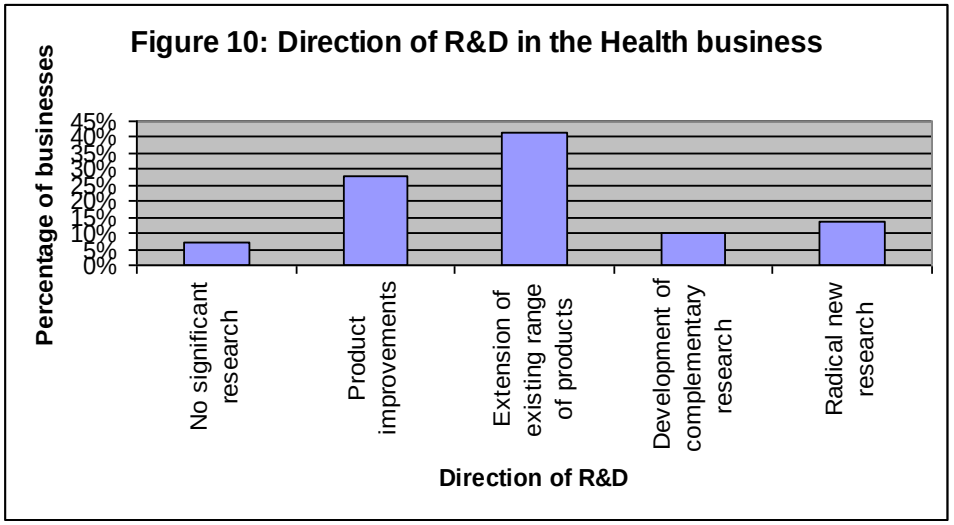


Similarly, R&D expenditure as a percentage of the total turnover of the business is shown in Figure 9.



For seven companies R&D expenditure as a percentage of the total turnover was 0, ten companies had a percentage of 1-10, three companies 11-20, two companies 21-40, four companies 41-60, one company 61-80 and two companies 81-100. Regarding businesses investing in R&D for thirteen investment was increasing, for eight it was stable and for two it was decreasing. The main reasons for investment in R&D increasing were that there was a need to develop new markets, new clients and customers, more products and R&D was a main source of income.

Reasons for decreasing investment in R&D were no funding and a declining customer base. When asked whether R&D was essential to the company business model nineteen firms responded that it was and ten that it was not. Just over half the health businesses (51.7%) reported that the R&D they undertake is market oriented compared to 48.3% who commented that they were first developing new technologies/systems/products/services and then the market. Figure 10 shows the direction of R&D in the health businesses.



Two companies reported that there was no significant research, eight that there were product improvements, twelve that there was extension of the existing range of products, three that there was the development of complementary research and four that there was radical new research. Twenty of the health companies reported that they were undertaking R&D in partnership with NHS trusts, research organisations, universities, the Welsh Government, European Union, the Department of Trade and Industry, research councils and other (including the Wellcome Trust, private and public companies, Scottish Enterprise and the Department of Health). The other nine companies commented that they were not working with any organisations. The types of partnership they were involved in were academic research papers, Knowledge Transfer Partnerships (KTPs), consultancies, spin outs and health services research. Eight companies were in receipt of sponsorship or grant for R&D and twenty-one were not. Those who were in receipt of sponsorship included one of Europe's most successful R&D organisations with 31% of the total SME FP6 budget and those with funding and grants from WG, SMART CYMRU, the DTI Technology Programme and one with a Health Technology Devices grant.

On a rating of most important to least important the major influences on the commitment to R&D expenditure were reported as to remain competitive, followed by to develop intellectual property (IP), level of support available, to train staff and tax benefits. The least important influence on the commitment to R&D expenditure was business contract R&D. Thirteen companies owned 185 patents and seven had filed for 38 patents in the last 2 years.

- *Additional company observations on aspects of R&D*

The issues that health firms felt limited the R&D opportunities of the company were time constraints, inadequate skills and space restrictions. The least important issues were insufficient equipment, R&D not being a central aim of the company, limited desire by the company to undertake R&D, lack of financial resources and restricted research ideas. Companies reported that they published their R&D activities through internal reports (fourteen firms), external reports (two firms), company reports (six firms) and by other means (seven firms) (including papers by research partners in scientific journals and magazines).

Comparative analysis

- *The business*

Analysis of the total respondents to the study for the energy and health sector companies shows that the energy companies are fairly young with an average age of 18.3 years (16 companies 0-10 years old) similar to the health companies with an average age of 17.6 years (12 companies 0-10 years old). With regard to the number of full-time employees there were fourteen energy companies with 1-9 employees (58% micro) and twelve health companies (41% micro). Most businesses were limited companies (18 energy, 75% and 23 health, 79.3%). For the activities of the businesses thirteen energy companies (54.2%) were in the main energy activity areas and twenty-one companies were in the principal health activity areas (72.4%). Six energy companies (25%) and seven health companies (24.1%) had turnover of under £100,000 and both the energy and health sectors had companies with over £5 million turnover (16.7% and 24.1%, respectively).

- *Specific factors relating to R&D work*

For both the energy and health sectors there were firms undertaking basic/fundamental research (two energy companies, 8.3% and four health companies, 13.8%) with four energy businesses (16.7%) developing new technologies and eleven health businesses (37.9%) developing new products. Three energy companies (12.5%) and fourteen health companies (48.3%) had a dedicated R&D department. Fourteen energy companies (58.3%) had no QSEs (9 had 1-20, 37.5% and 1 had 61-80, 4.2%), six health companies (20.7%) had none (thirteen had 1-20, 44.8%, three 21-40, 10.3%, three 41-60, 10.3%, one 61-80%, 3.4% and three 81-100, 10.3%). The total level of R&D expenditure showed that twelve energy (50%) and seven health (24.1%) companies had no expenditure on R&D and ten energy (41.6%) and seven health companies (24.1%) spent between £1-50,000 on R&D (6 health companies, 20.7%, spent over £500,000). This was reflected in R&D expenditure as a percentage of total turnover. Eight energy companies (33.3%) and thirteen health companies (44.8%) reported that their investment in R&D was increasing. Four energy companies (16.7%) and two health companies (6.9%) reported no significant research and four energy (16.7%) and four health (13.8%) companies reported that the direction of R&D involved radical new research. Six energy companies (25%) and ten health companies (34.5%) undertook R&D in partnership with a university, one energy company (4.2%) and seven health companies (24.1%) with the Welsh Assembly Government, two energy companies (8.3%) and two health companies (6.9%) with the European Union and four energy and four health companies (16.7% and 13.8%, respectively) with other organisations. Partnerships companies were involved with included academic research papers, KTPs, consultancy and spin outs for both energy and health companies. Major influences on the commitment to R&D expenditure were to remain competitive and to develop IP for both energy and health companies (the level of support was also important). Only three companies in the energy sector had patents and thirteen in the health sector.

- *Additional company observations on aspects of R&D*

Time constraints were identified by both energy and health companies as an issue that limited R&D opportunities. Internal reports were identified by the sectors as the most important process by which the company reported R&D activities.

CONCLUSIONS

Two considerations of major importance to the Welsh Government are what will be the policies needed to guide the scientific and technological R&D efforts of the Welsh economy and how the Government can organise science policy programmes and initiatives. Two sectors that have been identified as being of significance in their R&D activity to the future economy of Wales are energy and health (WAG 2006a&b). In response to the research question "what is the capacity of Wales to become a World leader through the exploitation of R&D activities in both academia and industry" it appears, from the evaluation of R&D in Wales undertaken in this paper, that there is a need for selectivity and concentration of resources into those sectors such as energy and health where Wales has a critical mass of research and resources which have the potential to be developed to a World class level. The current levels of research activity in these areas have the capacity to be developed if the right science policy decisions are made. In relation to this potential there are certain R&D requirements in these sectors that need to be provided for. These are evidenced in the research findings of the study undertaken into the energy and health sectors described in this paper. The main objective of the initial pilot study was to test the research instrument developed. As a result, certain adjustments were made to achieve a higher response rate for the full survey.

The relevance of the research findings to the conclusions is to provide insight into the impact of local R&D on the energy and health sectors in Wales.

Since Wales is an "open economy" a major policy question concerning R&D work is the extent to which indigenous technology progress is created by local R&D or by developments globally (Revesz and Boldeman, 2006). Needless to say, the economic impact of R&D work on the Welsh economy will be of considerable importance. The research examined this policy question. Within the economy there will be a number of methods used by enterprises to protect the competitive advantage of their new or improved processes and products. A major influence on the commitment to R&D programmes identified in the study of firms in the energy and health sectors in Wales was to develop intellectual property (IP). Small enterprises in markets will often need patents in order to release new products (Mazzoleni and Nelson, 1998) and this is evidenced in the study through patents being taken out by a small percentage of the companies surveyed.

There is an argument that a small nation like Wales will receive most of its technology innovations from other countries and with competitive conditions indigenous small and medium-sized enterprises (SMEs) will have the incentive to adopt exogenous new technologies without Welsh Government support. Indeed, at a qualitative level there will be the case both pro and ante for R&D government support and quantitative analysis is required to determine R&D subsidies at an optimum level (Revesz and Boldeman, 2006). A number of surveys in the literature have considered time delay and it was found that time constraints were identified by both energy and health companies as an issue that limited R&D opportunities in the results of the survey.

Public schemes for R&D activities can include subsidies for business R&D, research by public bodies (especially universities) and IP protection. In the study six energy companies and ten health companies reported that they undertook R&D in partnership with a university. R&D in universities has the important aim to provide postgraduate students with research skills and related to this public R&D creates considerable knowledge spillovers to business through "tacit" knowledge, training of researchers and collaborative ventures. For both the energy and health companies in the survey the partnerships companies were involved with included academic research papers, Knowledge Transfer Partnerships (KTPs), consultancies and spin outs. A significant policy question for R&D activity in a small open economy like Wales is to what extent domestic technology progress is influenced by global developments or domestic R&D work. It appears from the results of this research that domestic technology progress in Wales is influenced by both global developments and domestic R&D.

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