South Africa's Energy Future: An Analysis of Government Policies and Strategies

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Abstract During 2008 the South African economy paid a heavy price after the national electricity utility, Eskom, was forced to initiate energy load-shedding that included a full black-out of the South African mining industry for a few days, the cost of which ran into billions of Rands. The South African Government responded with a number of energy policy and strategy documents all of which attempt to guide the country towards improved energy security. One such policy document, known as the "Integrated Resource Plan of 2010", or more commonly the "IRP2010" provides a road map towards a more sustainable energy future by expanding the current installed capacity from about 42 GW to 85 GW by 2030 and at the same time reducing the country's dependence on coal resources. This policy document was approved by the South African Cabinet during March 2011 and was formally promulgated as South African government policy during May 2011. This paper takes a critical look at the Government's various policy and strategy documents with a view on what is realistically possible and the University of Pretoria's response to this. This is done from a systems engineering perspective, highlighting the complexity of ensuring national (electrical) energy security.

Introduction

Until about 2006 South Africa was seen as a country with abundant and cheap energy resources. Coal was seen as an infinite resource for electricity generation and although the country has some hydro-electrical and the only nuclear power station on the African continent, there was little reason to move away from coal as the dominant energy source. This changed in late 2007 when Eskom suffered a number of unplanned plant outages, together with a higher than expected economic growth rate, this created what one could argue was the "perfect energy storm". During 2008 the country suffered rolling blackouts (somewhat diplomatically referred to as "load-shedding") that even saw the key mining industry being cut off from electricity supply for a while. The effect on the economy was huge, and in some cases industries still have not fully recovered from the subsequent economic fallout. The economic impact on the GDP of South Africa was in the order of R200 million per day while the loss to the mining industry during the time it was shut down was claimed to be R250 million per day, (Calldo 2008). These events, together with increased pressures to substantially reduce greenhouse gas releases, led to a fresh look at what the energy future of South Africa should look like. Amazingly, government sources stated at the time that these power black-outs will have no effect on the country's economic growth figures, (Calldo 2008). This despite a subsequent admission by government that the loss in tax income over this period amounted to R5.9 billion, (Calldo 2008).

During and after the blackouts of 2007 and 2008 a number of government policy and strategy documents were released that are clearly aimed at taking the country towards a more secure energy future, notably the Nuclear Energy Policy, approved by Cabinet during 2008, (Department of Energy 2008d), and Integrated Resource Plan. Of the latter, the first version, generally known as IRP1, was published in the Government Gazette during December 2008, (Department of Energy 2008a), the second version was published in draft form for public comment during October 2010, and is generally known as IRP2010, (Department of Energy 2010b). Others included the Industrial Policy Action Plan, known as IPAP2 and in force since April 2008, (Department of Trade and Industry 2008), the Energy Efficiency and Demand Side Management Policy, known as EEDSM and published in May 2010, (Department of Energy 2010a), and the Nuclear Research, Development and Innovation Strategy, known as NERDIS, currently in draft form being reviewed by the Department of Science and Technology, with a final version expected by late 2012, (South African Nuclear Energy Corporation 2010). All of these have in common the issue of energy security and its contribution to job creation, economic growth, research and human capacity and skills growth. These are also underpinned by the Department of Economic Development's New Growth Plan, a draft of which was released during November 2010, (Department of Economic Development 2010).

With a view of these and the importance with which the South African Government views energy security of supply and its positive contribution to climate change, (Department of Environmental Affairs 2010), it is evident that an opportunity exists for focused energy-related research as well as the training of scientists and engineers in the field. The University of Pretoria has in the last few years been involved in a number of energy related research activities, notably with regards to Energy Efficiency, Demand Side Management, Fluoro-materials, Carbon Materials, Nuclear Energy, Advanced Materials, Thermoflow as well as Engineering & Technology Management. This, coupled with the fact that the University houses the largest engineering faculty in South Africa and the only graduate school of technology management in South Africa, places the University in a unique position to leverage its well-developed and highly rated scientific, engineering and management capabilities in support of Government's energy objectives.

Energy Policy Analysis

A recent study by Prof Anastassios Pouris, Director of the University of Pretoria's Institute for Technological Innovation, found that, between 1997 and 2007, the University of Pretoria has been the most prolific South African publisher of core energy research, (Pouris 2008). Hence the university is already well-positioned to become one of South Africa's key energy research institutions and to make an important contribution to the realization of the South African government's energy plans.

Over the last year the university has evaluated relevant government policies and strategies pertaining to the wider energy theme in South Africa and concluded that a focused and concerted research effort is necessary to support the country in achieving the goals of the latest version of the Integrated Resource Plan, generally referred to as the IRP2010, (Department of Energy 2010b). This would require a proper "big picture" or systems research vision, failing which the IRP2010 will just become another fragmented, forgotten and unsuccessful government strategy. Analysis of the IRP2010, together with a plethora of other government policies and plans, all mentioned earlier, has led the university to conclude that a number of sub-themes in the wider energy theme need to be urgently addressed. These sub-themes include:

Energy Production

Nuclear; it is evident that South Africa cannot achieve its declared reduction in green-house gases and base load requirements without expanding the contribution of nuclear power to the national power mix. The approved Integrated Resource Plan, (Department of Energy 2010b), makes provision for at least 6 new nuclear power stations. At the same time the Koeberg facility will soon start with a major project to extend the lifetime of the plant. Despite the ongoing problems in Japan a number of countries (China, Finland, United Kingdom, United Arab Emirates, etc.) are also engaged in major nuclear projects, providing for research collaboration opportunities.

The following is indicative of international nuclear energy trends:

Table 1 International Nuclear Trends (Source: www.world-nuclear.org, 2010)

Currently operating reactors	440
New reactors proposed	344
New reactors planned (order placement imminent or on order)	149
New reactors under construction	59

The nuclear area is of particular importance to the University, emanating from its participation in research projects for the Pebble Bed Modular Reactor (PBMR) Programme. These projects benefited the University in a number of areas, including laboratory upgrades, new state-of-the-art equipment, new research skills and know-how in the nuclear field.

Coal; South Africa currently sources nearly 90% of its energy needs from coal, which in turn is responsible for the bulk of the country's greenhouse gas releases. The University, through its South African Research Chair Initiative (SARChI) Chair of Carbon Technology & Materials and the Institute of Applied Materials, already is involved in addressing this problem, notably with a focus on so-called "clean-coal" research. In addition the two new coal-fired power stations, Medupi and Kusile, currently being constructed by Eskom both provide exciting research opportunities during their planned 40 year operational life cycle. Important areas of research would be the underground gasification of coal, carbon dioxide (CO_2) capturing & storage as well as clean coal.

Renewable Energy; it is the declared intent of the Government to drastically increase the contribution of especially wind and solar resources to the national energy mix with the anticipated contribution of these energy sources to approach 50% of all newly constructed capacity within the next 20 years, (Department of Energy 2010b). As these technologies are also relatively new and in some cases rather novel, much research scope exists for the new initiative. Examples include the planned new 5000 MW Solar Park at Upington and the soon to start 100 MW Concentrated Solar Plant and 100 MW Wind Farm projects by Eskom.

Energy Distribution

Smart Grids; with the inclusion of non-traditional energy resources such as renewables with their inherently random availability it becomes substantially more important to also move towards so-called intelligent (or smart) distribution networks. As South Africa has barely touched this field opportunities abound for advanced research. In fact, once many of the anticipated new solar and wind plants are going online the country will have little choice but to invest into the upgrade of its current distribution network and move in the long-term to a smart grid. This would include research opportunities in areas as diverse as software engineering, control engineering, systems modeling & simulation, advanced distributed sensing & measurement, secure communications, and protection systems, all of which the university is well-placed to address. An interesting impact on the existing network would be a growing fleet of electric motor vehicles, especially with the pending release of such vehicles on the South African market by manufacturers such as Nissan, Toyota and General Motors, and possibly the locally developed Joule vehicle.

Energy Storage; renewable energy sources are generally viewed as not exhibiting base load capabilities, i.e. they are dependent on whether the sun shines (solar generation) or whether the wind blows (wind generation). When the sun however does shine or the wind does blow it is also quite plausible that there is no consumer need for the energy generated by these plants. A solution to this would be the ability to efficiently store energy when not needed and later to release it when needed, independent of whether the sun shines or the wind blows (the random availability of sun and wind energy has an effect on the national electricity distribution network as well).

Energy Optimisation

Energy Efficiency and Demand Side Management (EEDSM); the university currently hosts the National Hub for EEDSM within the Centre of New Energy Systems. It continues to attract many postgraduates from across the country, as well as an increasingly strong contingent of international students into its programmes in energy efficiency. With its strong research track record, the Hub has been recognized as a leader in EEDSM research contributing to the alleviation of South Africa's energy problems.

Plant Lifetime Extension; most power stations were designed (and still are) to last a relatively long lifetime, typically 40 years, after which they are decommissioned and dismantled. Due to financial pressures and other reasons many older plants are currently being upgraded to extend their lifetime expectancy, sometimes by 20 or more years. This poses particular problems with regards to engineering management, safety issues, materials longevity and maintenance. Examples in case include the pending Koeberg life extension programme. The University has excellent capabilities in these fields.

Thermal Optimisation; thermal efficiency is the key to optimised power plants. This is relevant to almost all energy plants, whether coal, nuclear, or solar (wind power being the exception). The university hosts the largest South African research group in this field and is known for its leading-edge thermoflow know-how.

Advanced Materials

Carbon & Graphite; The SARChI Chair in Carbon Technology and Materials within the Institute of Applied Materials (the latter being a joint effort between two university faculties (Engineering, Built Environment & Information Technology, and Natural Sciences & Agricultural Sciences) and the SARChI Chair in Fluoro-materials Science

& Process Integration (all residing within the university's Department of Chemical Engineering) are on the leading edge of specialist materials research in South Africa. Further research is also been done by the university's Departments of Chemistry and Physics in computational materials modeling of leading-edge materials using the University's state-of-the-art cluster computing facility.

Ceramics; Silicon Carbide (SiC) plays a critical role in high temperature nuclear reactors. It turns out that this particular material is also being viewed with increasing interest by more traditional nuclear reactor designers, particular as a material for cladding in fuel elements to replace existing Zircalloy (this material reacted with steam in the Fukushima Daiichi event, creating hydrogen which then exploded). Other applications such as high temperature heat exchangers are also possible. The university already is regarded as an international expert institution in the use and characteristics of SiC.

Composites; although composite materials traditionally are viewed as important in automotive and aerospace applications, recent developments also demonstrated their applicability in the energy field. One example would be the use of such materials for nuclear reactor control rods. Other possibilities also exist, e.g. turbine blades for wind energy systems.

Heat-resistant Materials; the issue of materials resistant to high temperatures enjoys substantial research interest. Applications of these materials range from nuclear applications to solar energy systems.

Material Characterization; the University has a world-class capability to do advanced and novel characterization of materials. No research in advanced materials would be possible without the ability to determine the composition, structure, defects and behavior of materials under specific conditions.

Materials Modeling; modeling of the properties of materials has reached such an advanced state that it is more productive to first calculate desired properties of advanced and exotic materials rather than to embark on expensive and time-consuming experimental investigations. The University of Pretoria is already recognized as a leader in this field with excellent computational hardware and the most modern software in the field.

Policy, Economics & Society

Manufacturing Localisation; it is quite clear that the roll-out of new energy capacity, (Department of Energy 2010b), would be hugely challenging for the South African manufacturing industry. The doubling of current installed generation capacity from about 42 GW to 85 GW will require the large up-scaling of the local manufacturing industry, not only from a skills perspective but also from design, engineering management, manufacturing process, capacity and facilities perspectives, (Department of Trade and Industry 2010).

Legal & Regulatory; past experience illustrated the catastrophic effects on projects in the energy domain when specific legal and regulatory aspects are not properly addressed. What makes this so challenging is the fact that many energy technologies have surged ahead of the existing legal and regulatory frameworks. Areas of particular importance include carbon trading, compliance to environmental undertakings such as the Copenhagen Accord, (Department of Environmental Affairs 2010), legal frameworks for energy regulators, etc.

Health & Safety; generally it is understood that health and safety is important in nuclear energy plants. But clean energy sources such as solar and wind also have health and safety challenges, notably with regards to heavy and other exotic materials that find extensive use in these plants.

Dynamic System Modeling; the scope of the modeling of energy systems and their building blocks can range from the development of detailed mathematical models that can be used to predict particular physical phenomena, to high fidelity complete dynamic system models (e.g. a complete power station) used for the study of accident and operational behavior as well as operator training, to atomic level computational models. Also included would be economic models that are typically used by governmental and utility organizations to do financial prediction and help determine policy. This field is vast and complex and truly multi-disciplinary, requiring expertise from the mathematical, physical, management and materials sciences as well as engineering & business management sciences.

Design Life Cycle; it is widely accepted that all successful system solutions exhibit some, if not all, of the characteristics of a total life cycle approach. That is, not only are the basic design processes part of the system's creation, but also all elements required to support, maintain, expand, and eventually discard the equipment in a safe and environmentally friendly manner. The university is fortunate in that the Graduate School of Technology Management's senior academic and research personnel all have vast practical and industrial experience of the field. In addition, the School also hosts the Chair in Life Cycle Engineering.

Risk Management & Mitigation; as South Africa embarks on the difficult path towards energy security not only would this path be fraught with engineering, scientific and economic problems, but also many risks. Many large capital intensive undertakings fail in some way or other due to a poor understanding of the inherent risks. The very fact that South Africa has serious problems with reliable and sufficient energy sources can be attributed to poor risk management. There are clear needs for practical risk management models that can be used to mitigate the energy supply risks South Africa currently faces, especially as this must be seen within the contradictory requirements of both an increased energy supply capacity and reduced release of greenhouse gases.

Techno-economic Analysis; with the focus on sustainable energy solutions also comes a question on future trends. As technologies tend to cross traditional borders and energy plants become a complex multi-disciplinary "consortium" of technologies it also becomes important to analyse technology trends and their economic impact. This would be a critical enabler for national energy policy makers.

Sustainability; of primary concern is the sustainability of energy sources and by default the resulting systems. This is true not only from a social and economic perspective, but also from a scientific and engineering viewpoint. The long-term limited reserves of coal as an energy source are well-known, as is the case with uranium. On the other hand, the belief that renewable sources such as wind and solar are unlimited is a fallacy as the required wind and solar electricity generating plants also use other limited sources (e.g. rare-earth materials of which almost 95% of known world reserves are found in China). The subject of energy system sustainability seems to be focused on mainly renewable sources. This is a severely limited outlook of what should be a much richer and larger research field.

Environment

Waste Management; the university is currently engaged in a novel nuclear waste research project that makes use of bacteria to remove certain radio isotopes from high-level radioactive graphite waste (the results of which form part of a European Commission Framework 7 Project, called Carbowaste). Furthermore, one of the most contentious issues in nuclear energy remains the long term storage of radioactive waste. Currently glassy carbon is being investigated by the university as an alternative storage solution for high-level nuclear waste.

Pollution; it is clear that despite the South African Government's ambitious promises to reduce the country's Green House Gas release by 42% within the next 15 years, (Department of Environmental Affairs 2010), this goal will in all likelihood not be achieved. Almost all of the current energy sources pollute the environment in some way providing vast scope for research. This is underlined by the fact that South Africa only ranks 115 out of 163 countries in the 2010 Environmental Sustainability Index as published by the Yale University Centre for Environmental Law and Policy, (Yale 2010).

Role of Systems Engineering

This study has shown without any doubt that a nation's energy system is probably one of the most complex system-of-systems one can imagine. Not only is it very much in the economic and political domains, but it also is extremely complex from a technical/technology viewpoint. Complicating matters the last few years has been the growing focus on environmental issues. This has become such an issue that it now is almost impossible to focus solely on energy technologies without linking it to climate change, thereby including a space largely dominated by the United Nation's Intergovernmental Panel on Climate Change (IPCC), various environmental NGO's and environmental activist organizations such as Greenpeace, and international politics.

At the higher level the drivers of a national energy system-of-systems include the Environment, Economics and (Energy) Security. This is typically represented by the "Energy Triangle" as shown below. This example shows a selected system that is overwhelmingly leaning towards its economical performance only.

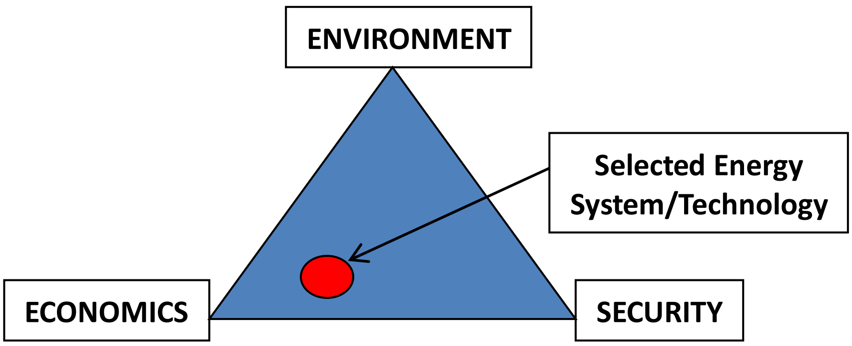

Figure 1 Positioning a Chosen Energy System Solution Within the Energy Triangle

Of course, should one decide that environmental issues outweigh energy security issues one could move the system position more towards the environmental point but away from the energy security point. This simply illustrates that, as with all other design choices, a selected system in the end is the result of a compromise.

It is evident that it is important to consider a national energy system holistically, especially when it comes to policy, investment and technology decisions. It would appear that the South African government's future energy decisions will be largely driven by the IRP2010 plan. An open question that does remain though is how well, if at all, the systems engineering aspects were addressed during the development of this plan. On face-value the plan appears to provide for a reasonable mix of energy technologies, but when analysing it in more detail a number of questions arise.

To address these one needs to look in some detail at the energy value chain. Until recently this value chain was rather simplistic as shown below.

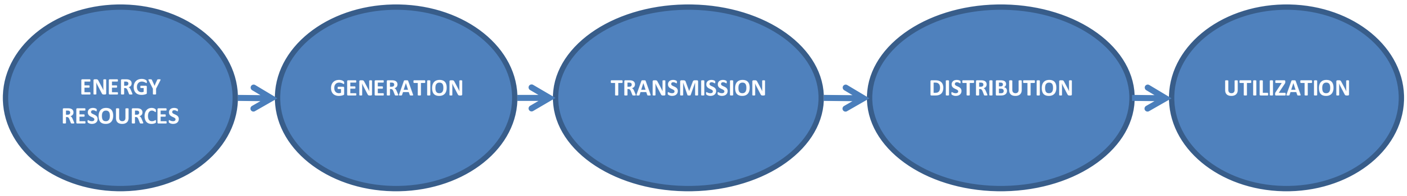

Figure 2 Old Energy Value Chain

With the growing contribution of renewable energy systems to national transmission grids their inherent randomness has started to impact on grid stability. This leads to new research focus areas such as so-called smart grids and energy storage. The impact this has on the value chain is shown below.

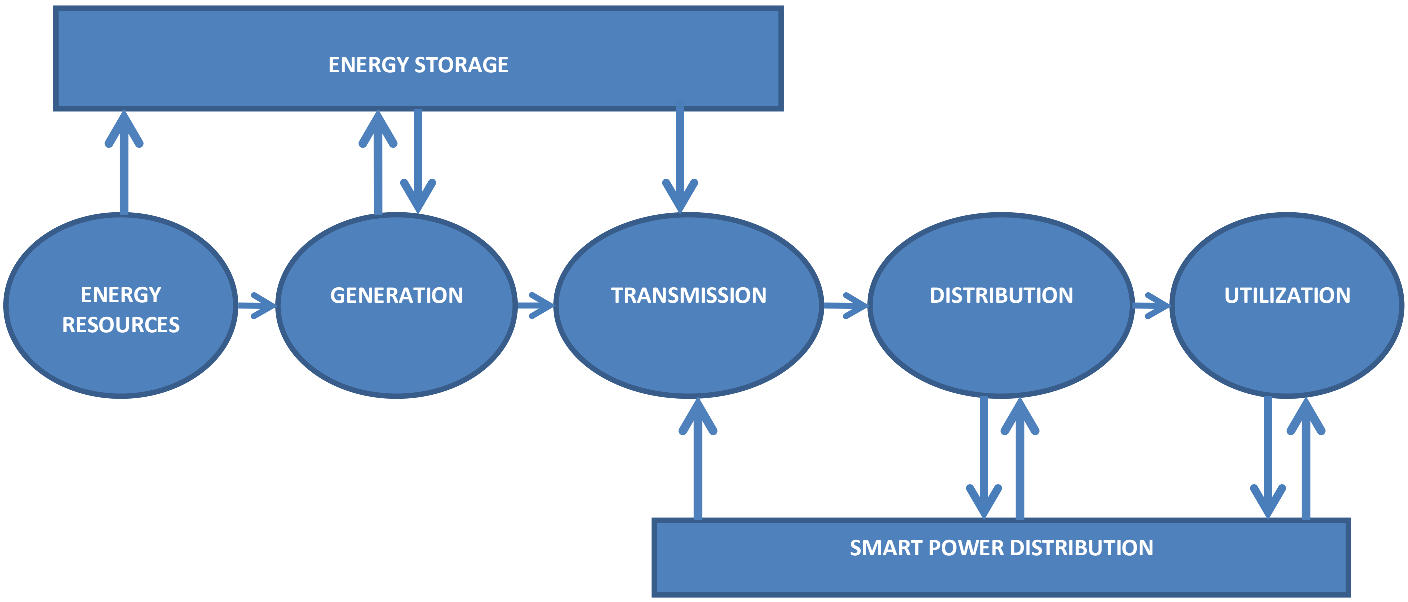

Figure 3 New Energy Value Chain

Drilling down into each of these main focus points would reveal the underlying complexities, for example it has long been believed that a resource such as wind together with wind turbines would contribute to lessening the effects of man-made climate change. Recently however, research by Liming Zhou, Research Associate Professor at the Department of Atmospheric and Environmental Sciences at the University of New York, found that according to satellite data large wind farms in Texas do in fact contribute measurably to local climate warming due to the turbulence caused by the large turbine blades. Temperature increases up to 0.72°C/decade were observed, (Zhou 2012). Furthermore, it is suggested that large wind farms would have a long term effect on local wind and weather patterns, (Gray 2012). Other aspects that come to the fore include transmission system instabilities caused by the random nature of especially wind generation. Point is, without a proper systems engineering effort, supported by relevant modelling actions, the new, supposedly environmentally friendly technologies such as solar and wind, could have unintended negative impacts on both efforts to stem climate change and the security of energy supply. Following this would be accompanying negative economic effects.

Perhaps a good example of the disastrous impact of not following any holistic thinking lies in the following quote by the previous South African President, Thabo Mbeki, during the 2008 electricity black-outs, (Calldo 2008):

"When Eskom said to the government :We think we must invest more in terms of electricity generation'… We said not now, later. We were wrong. Eskom was right. We were wrong."

His comments referred to a 1998 white paper that refers to an analyses by Eskom that indicated that, without new power stations, South Africa would enter a period of energy shortages by 2006, (Department of Mineral Affairs 1998). In this white paper Eskom was essentially forbidden to build new capacity and it was stated that new capacity should only be supplied by private enterprise. The cost of any large base load power plant meant that this policy was doomed to fail and it was eventually withdrawn by 2004. This was unfortunately too late to prevent the 2008 black-outs.

Project Selection

It is impractical and perhaps unaffordable to activate many research projects only because they appear to generally fit the sub-themes described earlier without ensuring that these do in fact contribute directly to South Africa's future energy security. It is evident that an optimum portfolio of research projects need to be developed that would support the larger energy security requirement but which at the same time also fit well into the university's existing know-how set. For this a modified GE-McKinsey portfolio selection matrix is proposed. This is shown by figure 4. As most tools of this type, the eventual project selections will rely on the insight and understanding of individuals, including those from the local energy sector. However the proposed tool attempts to minimize personal bias by the use of two selection parameters, namely the research activity levels in a particular research area by the university versus the alignment of such research activities to the energy objectives of government and industry. Additional to the proposed tool use will also be made of the outputs from a current project on energy technology assessment currently active within the Graduate School of Technology Management.

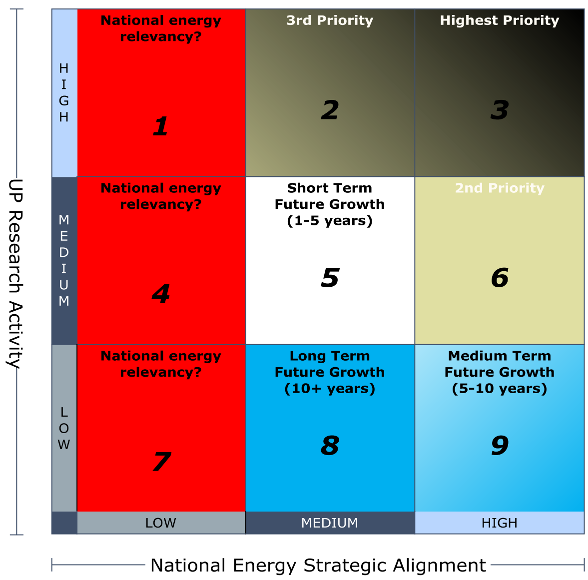

Figure 4 Modified GE-McKinsey Project Selection Matrix

Conclusion

Analyses of the South African government's electrical energy strategies, policies and plans highlighted a number of shortcomings, but at the same time these shortcomings also provide universities with excellent research themes. Chosen correctly these themes can contribute to a large extent to ensuring South Africa's future energy security and capacity expansion plans as reflected by the IRP2010, (Department of Energy 2010b). This paper linked the identified research themes with existing research know-how at the University of Pretoria, and proposed a tool, based on a modified GE-McKinsey Portfolio Selection Matrix, to support the selection of specific research projects. The outcomes of the projects within the university's energy research portfolio would not only support the country's future energy security but would also be useful in updates of the IRP2010, (Department of Energy 2010b). The latter is currently the only indication of the South African government's official position on the country's electrical energy growth path to 2030.

The analyses results discussed by this paper also forms the basis of the new Energy Institutional Research Theme, one of a small number of high impact flagship research themes partially funded by the University of Pretoria.

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Biography

Jörg Lalk is a professional engineer with four degrees in electrical and electronic engineering, including a PhD from Cranfield University in the United Kingdom. He currently is a senior lecturer at the University of Pretoria’s Graduate School for Technology Management where he also is the coordinator of the university’s new Energy Institutional Research Theme. Prior to this he held various senior management and systems engineering positions in industry. He has more than 30 years’ experience in systems engineering, engineering management, project management and the management of strategic technology programmes in aerospace, automotive, ICT and consulting. He has been one of the founding members of the South African Chapter of INCOSE, served as chapter Vice-president during 2004, Chapter President during 2005 and Membership Board Member for INCOSE Region 3 during 2006. He is a Senior Member of the IEEE and has completed the UNISA Intellectual Law Specialization Programme with distinction during 2010. Outside of his professional activities his interests include DIY and all things equestrian.