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The importance of iteration and deployment in technology development: A study of the impact on wave and tidal stream energy research, development and innovation

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HIGHLIGHTS

- Technology up-scaling should take place after a formative phase of development.
- Ocean energy technologies are attempting to bypass a formative phase.
- Unit up-scaling has taken place prior to successful technology demonstration.
- The cost of the formative phase may be insurmountable using MW-scale technology.
- A shift in the research, development and innovation environment is necessary.

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ABSTRACT

The technological trajectory is the pathway through which an innovative technology develops as it matures. In this paper we model the technological trajectory for a number of energy technologies by analysing technological change (characterised by unit-level capacity up-scaling) and diffusion (characterised by growth in cumulative deployed capacity) using sigmoidal 5 Parameter Logistic (5PL) functions, observed and reported as a function of unit deployment.

Application of 5PL functions allows inference of technology development milestones, such as initiation of unit-level up-scaling or industry growth, with respect to the number of unit deployments. This paper compares the technological trajectory followed by mature energy technologies to that being attempted by those in the nascent wave and tidal energy sectors, particularly with regards to unit deployment within a formative phase of development.

We identify that the wave and tidal energy sectors are attempting to bypass a formative phase of technological development, which is not in line with technological trajectories experienced by historic energy technologies that have successfully diffused into widespread commercial application, suggesting that demand-pull support mechanisms are premature, and a need for technology push focused policy support mechanisms is vital for stimulating economically sustainable development and deployment of wave and tidal stream energy.

1. Introduction

Wave and tidal stream energy are, as yet, largely untapped renewable energy resources. Political will and favour towards wave and tidal energy has been strong within the UK, particularly in Scotland (Allan et al., 2011). Historically, the UK has been seen as the leader of the development of wave and tidal stream energy technologies (Ernst and Young 2013). The use of market pull incentive mechanisms such as Renewable Obligation Certificates have been attempting to stimulate technology deployment in the sector and development of a market for ocean energy devices (Allan et al., 2011), supported by a number of grant incentive mechanisms such as the Marine Renewables Proving Fund (MRPF) for pre-commercial prototypes (Jeffrey et al., 2014), and the Marine Energy Array Demonstrator (MEAD) and Marine Renewables Commercialisation Fund (MRCF) providing support for array

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demonstration and technology innovation (Vantoch-Wood, 2012).

In total, over £120 million has been allocated to the wave and tidal energy sector in the UK since the year 2000 (Research Councils UK, 2014). Much of the historic funding provided to wave and tidal energy to date has encouraged pre-commercial demonstration in an intense and challenging environment, but with a focus on units that are in the order of one megawatt in capacity (MacGillivray et al., 2013).

Whilst utility companies, and end users of electricity generated from the waves and tides, would benefit from the utilisation of large scale technology (which may be considered to directly correlate with larger levels of power production, increased revenue, and lower Levelised Cost Of Energy (LCOE)), the route to successful technology optimisation is not reached through the demonstration of a single unit prototype, or small samples of production. Rather, successful technology is demonstrated through the iterative process of experimentation, in order to understand what works well, and what does not (Thomke, 2003). Prototype costs are invariably significantly more expensive than the end commercial product, but well known cost reduction pathways have been followed within the solar PV and wind energy sectors (Junginger et al., 2010). However, progress down the pathway towards cost reduction is not instantaneous. Learning, a phenomenon well documented in studies and literature, is a function of unit deployment and not a function of time (MacGillivray et al., 2014; Junginger et al., 2010). As a result of a dearth of physical deployment, cost reduction through learning within the wave and tidal energy sectors is therefore restricted to theoretical analysis, making assumptions on future trajectories (MacGillivray et al., 2014; SI Ocean, 2013; Carbon Trust, 2011).

The ambition of the wave and tidal energy sectors has been to progress rapidly to medium-sized arrays, with utility and multinational equipment manufacturers heavily involved in technology development and project consenting process. Due to the scale of the financial requirements for these arrays, project finance through company balance sheets, bank loans, and perhaps most prominently public sector grants or loans are essential enablers – much in the way that more mature wind energy projects would be developed (Winskel et al., 2014). However, many of these early stage wave and tidal energy array projects are struggling to raise sufficient private sector finance in order to allow the projects to successfully engage with contractors and enter construction and operational stages.

From a technological development and diffusion perspective, wave and tidal stream energy technologies have not achieved the level of penetration into existing power generation networks that was initially expected, but there is nevertheless a very strong ambition to become an integral part of the future energy mix. These technologies are still considered nascent, and as such, require much development work, supported by strong technology-push policy mechanisms, to enable commercial operation to become a reality in the future.

1.1. Logistic growth functions

The logistic growth function originated as an extension of the exponential growth function, designed to constrain the maximum upper value of a given function or variable where limitless increase is deemed unrealistic (Tsoularis and Wallace, 2002). This limit, the saturation level, provides a numerical upper bound on the growth of the function. The explanation of population statistics within P.F. Verhulst's “Notice sur la loi que la populations suit dans son accroissement” in 1838 (Verhulst, 1838) is widely regarded as the first scientific contribution to the understanding of what is now known as the logistic equation.

The logistic growth model is able to reflect the changes in growth rate for a particular variable over time: the process follows a sigmoidal (s-shaped) profile where the rate of growth initially accelerates (and can be initially almost exponential in nature), before reaching a point of inflection and eventual deceleration in the rate of growth as a maximum limit is approached, as demonstrated in Fig. 1 below.

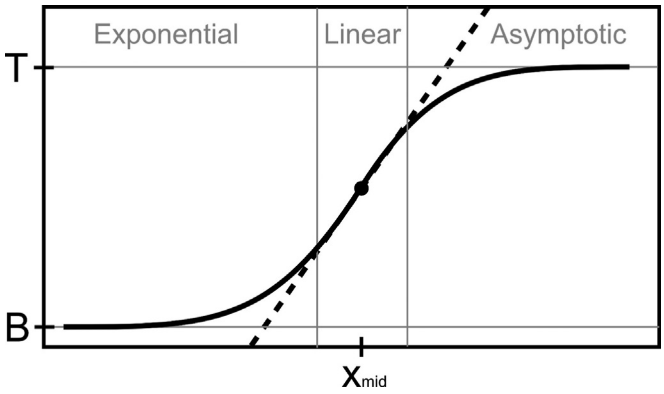

Fig. 1. Standard sigmoid (logistic) growth function.

A number of logistic growth models have been suggested as useful for modelling the growth of biological populations over time, but the application of these functions extends well beyond the fields of biology or social science (Tsoularis and Wallace, 2002).

Logistic growth functions have been used as a tool to characterise the diffusion of innovation across a range of processes and technologies. Diffusion of innovation theory emerged during the 1960s – but has since become a popular topic of research within many disciplines, including economics, statistics, marketing, sociology, psychology, and industrial engineering (Rogers, 1995).

Logistic growth functions have been applied to technological subjects such as the modelling of market penetration of new telecommunications services (Brewley and Fiebig, 1988), and the evolution of infrastructure in the USA – presented as percent of saturation level with respect to year for a number of technologies (Grubler et al., 1999).

Within the energy sector, application of logistic functions is utilised for the forecasting of technological change (Sharif and Islam, 1980), global energy usage change together with the senescence and substitution of older technology for more advanced sources of energy (Marchetti and Nakicenovic, 1979), and for the modelling of energy system growth and technology change based on empirical data (Wilson, 2012; Wilson et al., 2012), where the capacity penetration over time and the time-frames associated with development phases for of a number of energy technologies were considered. Forecasts of energy technology industry growth using logistic growth functions have suggested that a methane dominated energy economy could be in place by 2030 (Smil, 2008).

Existing research has considered application of 3 Parameter Logistic (3PL) models within energy sector technologies. 3PL functions provide curve-fitting through nonlinear regression models that are defined by three parameters: the maximum asymptote of the curve, the inflection point, and the gradient of the curve at the inflection point. The simplicity of the 3PL growth function can yield useful results when it is deemed an appropriate fit. However, it should be noted that there are some limitations to the use of simple 3PL functions, such as the strict enforcement of symmetry about the point of inflection (Brewley and Fiebig, 1988). Additionally, the diffusion process may occur at varying growth rates over the course of the sample (Brewley and Fiebig, 1988), an attribute that 3PL functions are unable to model accurately. 3PL